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# EFFECT OF AGRICULTURAL LAND USE PRACTICES ON STREAM WATER QUALITY: ECONOMIC ANALYSIS

by

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Effective management of agricultural nonpoint source pollution requires that economically feasible land use practices be selected and implemented. Since nonpoint source pollution from agricultural lands can be controlled by best management practices (BMPs), a food understanding of the response of farmers to incentive and regulatory policies is needed. This report provides an economic analysis of agricultural production activities and farmer response to water quality controls, using the Four Mile Creek Watershed in Iowa as a case study. The analysis showed that secondary tillage practices are important in designing cost-effective control strategies. Knowledge of perceived risk associated with practices is critical in determining farmer adoption of BMPs and response to control policies. Also, data on perceived opportunity costs of certain practices provided further understanding of farmers' reluctance to adopt those practices. A BMP evaluation framework that accomodates the scaling up from fields to watersheds ultimately was developed. The analysis showed that the marginal cost of soil loss control increased significantly as more stringent limits are adopted. Also it was determined that higher energy prices will likely enhance the effectiveness of soil loss control policies.

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# FOREWORD

As environmental controls become more costly to implement and the penalties of judgment errors become more severe, environmental quality management requires more efficient analytical tools based on greater knowledge of the environmental phenomena to be managed. As part of this Laboratory's research on the occurrence, movement, transformation, impact, and control of environmental contaminants, the Technology Development and Applications Branch develops management and engineering tools to help pollution control officials achieve water quality coals through watershed management.

Because the control or prevention of nonpoint source pollution is directed at site-specific management, it is essential that economically feasible Best Management Practices be selected. This report describes a project to evaluate farmers' response to incentive and regulatory policies that encourage the adoption of these land use practices.

William T. Donaldson
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# ABSTRACT

The effective management of agricultural nonpoint source pollution requires that economically feasible land use practices be selected and implemented. Since nonpoint source pollution from agricultural lands can be controlled by best management practices (BMPs), a good understanding of the response of farmers to incentive and regulatory policies is needed. This report provides an economic analysis of agricultural production activities and farmer response to water quality controls, using the Four Mile Creek Watershed in Iowa as a case study.

In an effort to address some of the limitations of the existing information base on the efficiency of BMPs, the investigation included four components. First, a watershed survey provided a profile of the farmers and the necessary data for the empirical analysis. Second, a BMP cost-effectiveness evaluation framework was developed and applied. Third, factors that are important in explaining the adoption of BMPs, such as perceived risk, were identified. Finally, the impact of increasing relative energy prices on crop management practices and on the effectiveness of nonpoint source pollution control policies was assessed.

The analysis showed that secondary tillage practices are important in designing cost-effective control strategies. Knowledge of perceived risk associated with practices is critical in determining farmer adoption of BMPs and response to control policies. Also, data on perceived opportunity costs of certain practices provided further understanding of farmers' reluctance to adopt those practices. A BMP evaluation framework that accommodates the scaling up from fields to watersheds ultimately was developed. The analysis showed that the marginal cost of soil loss control increased significantly as more stringent limits are adopted. Also, it was determined that higher energy prices will likely enhance the effectiveness of soil loss control policies.

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The responsibility for any remaining errors rests with the authors as do the opinions expressed in this report.

# I. Overview and Executive Summary

## A. Introduction

Society's concern for improving water quality is reflected in the Federal Water Pollution Control Act Amendments (FWPCA) of 1972 (PL 92-500) and in the Rural Clean Water Program (RCWP) of 1977 (PL 95-217). Section 208 of FWPCA-1972 requires states to develop areawide plans for controlling nonpoint sources of water pollution (including agricultural sources) and the RCWP provides the framework and funding for implementing the program. Since the control or prevention of nonpoint source pollution from agricultural land is directed at site-specific management, implying that compliance monitoring will be conducted on land rather than water, it is essential that economically feasible land use practices or Best Management Practices (BMPs) be selected.

Since the Environmental Protection Agency (EPA) has judged that nonpoint source (NPS) pollution from agricultural lands can best be controlled by BMPs, a good understanding of the response of farmers to incentive and regulatory policies is needed. The Four Mile Creek evaluation project is an attempt to develop the necessary information base.

Past NPS pollution control evaluation projects have relied on linear programming models, designed to maximize profits or minimize costs of control, have utilized secondary data sources in developing coefficients for the model and have assumed constant input prices.

Little attention has been given to the actual information or data used by farmers in forming perceptions of profitability. Typically, experimental data are used to identify the potential yield adjustments associated with different practices such as tillage, and representative cultural practices, such as frequency of tillage, are based on professional judgment. If farmers' yield expectations for new crop management practices differ from those employed in the model coefficients, the responses of farm operators to public incentives and regulations may be understated or overstated. Likewise, if the secondary data sources used in establishing the costs and returns coefficients do not represent the actual production environment, further bias will be introduced into the programming model results.

Past evaluations based solely on linear programming models also suffer from the assumption that only profitability matters to farm operators. Other factors, such as risk, may play an important role in farm management decisions. For example, if reduced tillage practices are more risky than moldboard plowing, other things equal, it may influence the adoption decision. If other objectives enter into the farm operator's decision function and if these factors are ignored, the linear programming results will not be accurate reflections of reality and may not be reliable for planning purposes.

In any modeling effort, the investigator must choose a set of input and output prices that reflect farmer expectations or professional judgment. Yet, relative price patterns, especially for inputs, may be changing over time and causing adjustments in the relative profitability of different crop management practices. For example, reduced tillage practices may become more profitable relative to moldboard plowings as energy prices rise over time. Such changes in relative prices, and in turn profitability, may induce adjustments in tillage practices that have favorable environmental inpacts. It is important not only to identify the environmental consequences of relative price changes but to recognize these adjustments when designing incentives and regulations to induce the adoption of BMPs.

In an effort to address some of the limitations of the existing information base on the efficiency of BMPs, our investigation includes four major components. First, the watershed survey provides a profile of the watershed farmers and the necessary data for the empirical analysis. Second, a BMP cost-effectiveness evaluation framework is developed and an application is illustrated. Third, factors that are important in explaining the adoption of BMPs are identified. Finally, the impact of increasing relative energy prices on crop management practices and on effectiveness of NPS pollution policies is assessed.

## B. Profile of Four Mile Creek Watershed

To establish a primary data base for the analysis, a survey of the Four Mile Creek farmers was undertaken by the project staff in March 1980. A five-section questionnaire designed to inventory machinery, crop management practices, livestock management practices, risk attitudes, and background information was administered. The objectives of the survey were to determine: (1) existing management practices, (2) how farmers would adjust their production practices given incentives, (3) coefficients for BMP evaluation and programming models.

A few findings of the survey, crucial to the economic analysis that follows, should be highlighted. First, as more erosive primary tillage practices were reduced, secondary tillage practices increased in the watershed. Thus the potential soil loss reduction attributed to the reduction of primary tillage operations may be somewhat overstated when farmers shift to conservation tillage. Second, watershed farmers expected the highest yields from fall tillage activities, followed by spring tillage, and then no-till. In addition to having the lowest expected yield, no-till had the highest risk rating assigned by farmers. Knowledge of perceived yield impacts of different tillage systems as well as perceived risk associated with practices is critical in determining farmer adoption of BMPs and response to NPS pollution control policies. Third, the data suggest that Four Mile Creek farmers tend to be risk neutral to risk averse in their behavioral preferences. Different formulations of risk questions were employed and relatively consistent responses were received. Finally, data on perceived opportunity costs of terracing, including both time and yield reduction costs, provide further understanding of farmers reluctance to terrace cropland.

## C. BMP Cost-Effectiveness Evaluation Framework

To evaluate the cost-effectiveness of alternative BMPs, an activity analysis framework is developed. The framework accounts for the various costs associated with different management practices and levels of residual control. Because the basic data units are 40-acre fields or plots, the impacts of scaling-up from fields to farms, farms to subwatersheds, and subwatersheds to watersheds can be evaluated.

The preliminary results indicate that contouring is the most cost-effective BMP of the subset considered. Yet, contouring is only effective as an erosion management practice over a relatively narrow range of residual control. In other words, contouring can reduce gross soil loss in the Four Mile Creek Watershed from 17 to 9 tons per acre per year, but no further. The same soil loss reduction with terracing or pasturing is far less cost-effective. Also, as supported by other studies, the marginal cost of soil loss (residual) control increases significantly as soil loss decreases regardless of the BMP imposed.

To compare and contrast the imposition of BMPs at different levels of aggregation, the Four Mile Creek Watershed was divided into five subwatersheds based on differences in soil type and erosion potential. Supporting the argument frequently made for targeting soil conservation funding, the average cost of reducing soil loss is significantly higher in subwatersheds with less serious erosion hazards. Put another way, specific BMPs are more cost-effective in areas with greater erosion hazards, other things equal. Further investigation of the implications of BMP targeting is needed.

## D. Adoption of Conservation Tillage Practices

Given the importance that EPA has placed on management practices for the improvement of water quality, it is important to understand why farmers do or do not adopt particular BMPs. Specific attention is given to the conservation tillage practice adoption decision. To isolate the factors that influence the adoption of conservation tillage practices (i.e., a BMP), a linear probability model of tillage choice is developed. The probability that a farmer will choose a tillage practice other than moldboard plowing is related to characteristics of the farm operator, including experience, tenure, education, and risk perceptions, and to characteristics of the farm, including field topography, crop rotation, and farm size.

The adoption model was fitted to 238 observations of primary tillage choice from the Four Mile Creek Watershed survey. The empirical results are very interesting and generally support the theoretical and intuitive foundations of our model. Additionally, these results should be useful in the design of more effective soil loss control policy. First, farmers with more education and experience have a higher probability of adopting conservation tillage practices. These results point to the importance of considering the human capital characteristics of farmers when designing education, incentive, and targeting programs to induce soil conservation practices.

Second, the structural characteristics of the farm operation produced some surprising results. Farm size is a negative factor in the adoption decision; the probability of adoption is inversely related to the size of farm operation. Even though larger scale operations have an incentive to acquire improved information because they can spread the costs over more units, smaller operations have a higher probability of adoption. Only if adoption of conservation tillage practices has negative scale effects or if it is generally less economic, would this result be expected. Existing experimental and survey data do not support these contentions. Contrary to the findings of some previous studies as well as to a popularly held belief, a more tenured operator (i.e., a larger share of owner-operated land) is not more likely to adopt conservation tillage practices than a less tenured operator. Economic theory supports the hypothesis that tenure should not matter if landowners are attempting to maximize the long run net returns to their investment.

Third, potential erosivity or field topography is a strong factor in explaining the probability of adoption as is to be expected; farm operators on hilly land have a higher probability of adopting conservation tillage practices. Additionally, failure to account for potential erosion problems may explain why previous studies found a significant positive relationship between tenure and conservation practice adoption.

Finally, differences in risk perceptions and expected yields are considered. Differences in risk perceptions influence the probability of adoption but the statistical significance of the result is somewhat weak. The result suggests that improved information directed toward developing more accurate perceptions of the riskiness of reduced tillage may be useful. Expected yield differences are not significant in explaining adoption but this result may be due to the small expected variation in yields in the region.

How far the results from the Four Mile Creek Watershed are generalizable is open to question, but they do indicate some potentially important factors that should be considered in designing future soil conservation programs.

## E. Effects of Rising Energy Prices on Nonpoint Source Pollution and Its Control

Changing relative input prices may confound the implementation of NPS pollution control options. Such price changes may complement the desired policy impacts, or alternatively, may compete with the policy objectives. Rising relative energy prices are of particular interest because of the impact of energy prices on the choice of tillage, rotation, and cultural practices. Thus, the formation of NPS pollution control policies should be cognizant of increasing relative prices of farm fuel and energy related inputs.

To assess the impacts of rising energy prices on soil loss and on the effectiveness of NPS pollution control policies, a linear programming model for the Iowa River Basin is used. Department of Energy 1985 and 1990 price projections for fuels are used to generate model solutions to compare with the 1978 baseline solution.

The overall policy implications are that higher energy prices tend to bring about shifts to practices which decrease both soil erosion and the amount of fertilizer used by farmers, even without encouragement from NPS pollution policies. These reductions are caused by a shift from continuous corn to corn-beans rotations and by a partial shift from fall chisel to no-till planting. Significant changes occur in both soil loss and net farm income by 1985, with 22 and 19 percent decreases, respectively. Little additional adjustment occurs between 1985 and 1990.

Combining the impacts of increasing energy prices and per acre soil loss restrictions, soil loss restrictions are only effective if soil loss is set at less than 10 tons per acre. Subsidies for soil loss abatement combined with increasing energy prices does provide ambiguous results. At lower subsidy levels, increasing energy prices will enhance the effectiveness of the subsidy policy, but at higher subsidy levels increasing energy prices may weaken the impact of the abatement subsidy. Generally, in the politically relevant range of subsidies as well as over the likely range of soil loss restrictions, higher energy prices will enhance the effectiveness of soil loss control policies.

## II. Profile of Four Mile Creek Watershed

### A. Introduction

The economic analysis of Best Management Practices (BMPs) is designed to forecast which BMPs will be selected by farmers under alternative policy options and to assist farmers in BMP selection. Generally, these evaluations have relied on budget analyses or linear programming models as the techniques of appraisal.

Two major problems arise in this approach to BMP evaluation. First, budgeting and linear programming analyses assume that the farmer's sole objective is to maximize profits or net returns. Yet, a number of other factors may enter the farmer's BMP adoption decision, including risk, experience, farm size, education, tenure, and perceptions. Although a number of these factors may contribute to profitability, clearly all do not. The exclusion of relevant variables from the objective function may result in biased results. Second, many of the coefficients used in previous budgeting and programming analyses were based upon secondary data sources. Coefficients derived from secondary data may not be representative of the actual farm production environment.

Given earlier data limitations, an extensive primary data collection effort was initiated in the Four-Mile Creek Watershed to provide the primary data base for the economic analysis. Unfortunately, premature termination of this project has prevented the initiation of some and completion of other components of the quantitative analysis.

The data that were collected provide useful background information on farmer attitudes and perceptions as well as on the farm production environment of the study area. To summarize the information obtained in the survey and to illustrate the intended uses of these data, a data profile is developed in the discussion that follows.

## B. Survey Design

The Four Mile Creek Watershed encompasses a nineteen square mile area in Tama County, Iowa. This east-central Iowa study area is a moderately sloping section of the Cedar River Basin. The principal land use is agriculture with corn and soybeans as the principal crops. The watershed has a range of erosion hazards and is quite representative of soils in the Corn Belt.

The Four Mile Creek Watershed was surveyed in March 1980. The objective was to determine how farmers in the watershed managed their crop and livestock activities and how they would adjust their production activities if additional incentives were provided for soil loss control.

A copy of the questionnaire used to obtain the necessary economic background information is contained in Appendix A. The questionnaire was distributed to all farmers in and adjacent to the watershed. Two weeks were allowed for completion of the form at the farmer's convenience. Telephone contacts were made with each interviewee to answer any questions that arose and to schedule a meeting to pick up the questionnaire. When the questionnaire was picked up, further assistance in completing the form was provided if needed. Forty-eight usable questionnaires were returned. The response rate in the watershed was 59 percent and encompassed 62 percent of the farmland. We were unable to detect any particular biases that may have been introduced by the less than 100 percent response, and we believe that the sample is highly representative of farming practices and behavioral response in the Four Mile Creek Watershed.

A sociological survey was simultaneously conducted in the watershed. Although this surveying activity was competitive and lowered our response rate, data exchange with the sociologists expanded the data base for this study. Some data from the sociology survey are included in the following discussion.

The profile is disaggregated into the five sections defined in the questionnaire:

I. Machinery and Implement Inventory
II. Crop Management Practices
III. Livestock Management Practices
IV. Risk Attitudes
V. Miscellaneous Farm Questions

Highlights from each section are emphasized in developing the agricultural profile of the Four Mile Creek Watershed. Also, the use of the data elements in the quantitative analysis is indicated.

As an introduction to the Four Mile Creek watershed, Table 1 shows farm size and organizational characteristics. The predominant organizational type was the single family farm. The two farms over 1280 acres were incorporated. Fifty-five percent of the respondents farming in the watershed operated between 160 and 640 acres. Table 2 presents the average size and tenure of land operated by each farm organization type. The average single family farm operated 378 acres;

Table 1. Farm organization and farm size in the Four Mile Creek Watershed, 1980

| Farm size | Single family | Related partnership | Single family corp. | Two or more family corp. | Row total |
|---|---|---|---|---|---|
| Under 160 acres | 5 | 1 | 0 | 0 | 6 |
| 161-320 acres | 11 | 1 | 0 | 0 | 12 |
| 321-640 acres | 12 | 4 | 0 | 1 | 17 |
| 641-1280 acres | 3 | 2 | 0 | 2 | 7 |
| 1281 acres and over | 0 | 0 | 1 | 1 | 2 |
| Column total | 31 | 8 | 1 | 4 | 44 |

Table 2. Land tenure and farm organization for the Four Mile Creek Watershed, 1980

| | Single family farm | | Related individual partnership | | Family corporation | |
|---|---|---|---|---|---|---|
| | Average acres | Percent owned* | Average acres | Percent owned | Average acres | Percent owned |
| Acres owned and operated | 158 | 42% | 140 | 24% | 345 | 31% |
| Cash-rent acres | 120 | | 325 | | 285 | |
| Crop-share acres | 114 | | 130 | | 488 | |
| Ave. acres operated | 378 | | 595 | | 1118 | |

*Percent of the land operated that is owned by this type of operator.

the partnership 595 acres; and the family corporation 1118 acres. Farmers operating in the watershed rented nearly two-thirds of the land that they operated. As a group, these farmers operated over 25,000 acres of land in 1979. Since the Four Mile Creek Watershed is 12,300 acres, few of the farmers surveyed operated entirely in the watershed. Operator status as tenant or owner (Table 2) may influence participation in a soil conservation program, given the shorter planning horizons of renters and the added complexity of lease arrangements incorporating conservation requirements.

### C. Machinery and Implement Inventory

An inventory of machinery and implement available to farmers operating in the watershed was collected. Type, age, size, and source (owned, borrowed, leased, or hired) information was collected on tractor, tillage, planting, weed control, fertilizing, and harvesting equipment. Although not summarized in this report, these data will be used to develop machinery complements for "representative farm" and individual farm programming models.

### D. Crop Management Practices

The Crop Management Practices section of the survey was divided into three parts. The first dealt with primary and secondary tillage practices employed by the farmers. The second surveyed estimated yields and perceived riskiness of different crop and tillage practices. The third gathered rotation yield data, corn yields with different insect control practices, and crop price expectations.

Tillage practices and timing of tillage for four possible cropping systems (continuous corn, corn after soybeans, corn after meadow, and soybeans after corn) on either level or hilly fields were determined from the respondents.

Conservation tillage activities used in research models frequently assume minimum use of secondary tillage practices. In actual practice, some farmers may substitute an increased number of secondary tillage operations for a reduction in primary tillage intensity. A significant increase in secondary tillage operations may offset both the potential soil erosion control benefit and the reduction in production costs and fuel use associated with conservation tillage.

Additional secondary tillage reduces the amount of crop residue. For example, a tandem disk incorporates one-half of the remaining residue with each use. The C factor for a typical corn-soybean rotation in the Four Mile Creek Watershed is .27 with 2000-3000 lbs of residue on the surface. The factor increases to .32 with 1500-2000 lbs residue, and to .39 with 1000-1500 lbs residue. The data in Table 3 illustrate the importance of residue management in controlling erosion in the Four Mile Creek and its subwatersheds.

Table 3. Soil loss with alternative residue levels in Four Mile Creek Watershed

| | Residue remaining per acre | | |
|---|---|---|---|
| | 2000-3000 lbs | 1500-2000 lbs | 1000-1500 lbs |
| | - - - - - - -tons of soil loss per acre- - - - - - | | |
| Watershed | 15.6 | 18.5 | 22.6 |
| Subwatershed 1 | 4.9 | 5.8 | 7.1 |
| Subwatershed 2 | 15.1 | 17.9 | 21.8 |
| Subwatershed 3 | 23.3 | 27.6 | 29.2 |
| Subwatershed 4 | 22.2 | 26.3 | 32.1 |
| Subwatershed 5 | 17.1 | 20.3 | 24.7 |

Table 4 shows the frequency of use of each of the primary tillage practices in the Four Mile Creek Watershed. Little variation exists in the frequency of tillage from level to hilly fields; possibly it is only economically feasible to maintain one machinery complement. None of the responding farmers used no-till planters.

Less than 30 percent of primary tillage is done with a moldboard plow in the Four Mile Creek Watershed. The moldboard plow is used mainly in the spring on meadow ground before corn and on beans after corn. The chisel plow is the dominant primary tillage tool used in the fall. Over 60 percent of primary tillage is done in the spring. These data suggest that further reductions in soil loss will require changes in crop rotations and management (e.g., contouring), the use of no-till planters, or the use of erosion control structures, given the widespread adoption of conservation tillage.

Table 5 indicates the secondary tillage practices that followed each primary tillage practice in the watershed. Given variable environmental conditions, the farmer may use a particular secondary tillage practice once during one year and twice the next year, accounting for the fractional values. Generally, secondary tillage increases slightly as primary tillage intensity decreases. The exception is with fall chisel plowing; the secondary tillage operations associated with this tillage practice are almost identical to those with fall moldboard plowing. These data also indicate that the chisel plow is replacing the moldboard plow, a consistent trend throughout much of the Corn Belt. For such a shift to be attractive to the farmer, the

Table 4. Frequency of primary tillage practices in the Four Mile Creek Watershed

| Rotation | | Moldboard | | Chisel | | Disk only | |
|---|---|---|---|---|---|---|---|
| | | Fall | Spring | Fall | Spring | Fall | Spring |
| Continuous corn | Level | 5 | 4 | 11 | 2 | 2 | 4 |
| | Hilly | 3 | 1 | 9 | 3 | 3 | 6 |
| Corn after beans | Level | 0 | 0 | 2 | 0 | 6 | 28 |
| | Hilly | 0 | 0 | 0 | 3 | 3 | 25 |
| Beans after corn | Level | 3 | 11 | 11 | 2 | 1 | 7 |
| | Hilly | 3 | 2 | 10 | 1 | 3 | 5 |
| Corn after meadow | Level | 4 | 17 | 3 | 0 | 2 | 0 |
| | Hilly | 1 | 14 | 2 | 2 | 0 | 1 |
| Total | | 19 | 49 | 48 | 13 | 20 | 76 |

Table 5. Frequency of secondary tillage practices by selected crops and primary tillage methods in Four Mile Creek

| Crop | Primary tillage | Secondary tillage practice | | | | | |
|---|---|---|---|---|---|---|---|
| | | Fall disk | Spring disk | Field conditioner | Harrow | Rotary hoe | Cultivate |
| Continuous corn | Fall plow | 1.0 | 1.0 | 1.5* | | 1.0 | 1.7 |
| | Spring plow | 0 | 2.0 | 1.5 | 1.0 | 1.0 | 1.8 |
| | Fall chisel | 0.5 | 1.0 | 1.5 | | 0.5 | 1.5 |
| | Spring chisel | | 2.0 | 1.5 | | 1.0 | 1.5 |
| | Disk only | | 2.0 | 1.5 | | 0.5 | 1.3 |
| Corn after beans | Fall chisel | | 1.0 | 1.5 | | 1.0 | 1.0 |
| | Spring disk | | 2.0 | 1.5 | | 1.0 | 1.5 |
| Corn after meadow | Fall plow | | 1.5 | 1.5 | 0.5 | 0.5 | 1.5 |
| | Spring plow | | 2.0 | 1.5 | 0.5 | 0.5 | 1.7 |
| | Fall chisel | | 1.5 | 0.5 | | 0 | 1.5 |
| | Disk only | | 2.0 | 2.0 | | 0 | 1.0 |
| Beans after corn | Fall plow | 0.5 | 1.5 | 0.5 | 0.5 | 0 | 1.5 |
| | Spring plow | | 2.0 | 0.8 | 0.5 | 0 | 1.5 |
| | Fall chisel | 0.5 | 1.5 | 1.0 | | 1.0 | 1.0 |
| | Spring disk | 6.5 | 2.0 | 1.0 | 0.2 | 0 | 2.0 |

*Fractional values represent average values over time.

cost-savings must be equal to, if not greater than, the yield penalty associated with fall chisel tillage. Also entering this economic decision is the effectiveness of weed control, which is a function of primary tillage choice, frequency of secondary tillage, herbicide use, and planting date.

Yield estimates with various tillage practices were requested from each farmer. The farmer was then asked to establish a range for that yield estimate. These deviations should identify possible non-symmetric distribution of yields for particular tillage practices. Also, the farmer was asked to give each practice a risk rating. These data can be used to evaluate tillage practice selection based on maximization of expected yield, maximization of highest yield, minimization of yield loss, or some other risk-related criteria.

As shown in Table 6, the highest yield estimates were associated with fall moldboard tillage, followed by fall chisel tillage, spring disking, spring chisel tillage, and no-till. The fall chisel tillage and spring disking had the lowest risk ratings. These were the most common tillage practices in the watershed. No-till planting had the highest risk rating, but the practice was not employed by the respondents.

The farmers expected a higher yield from contouring than straight-row planting for each tillage practice. Also, contouring received a lower risk rating and a narrower yield range. These results may indicate an awareness by the Four Mile Creek farmers of depositional damage from sediment run-off, seed bed washout, gullying, and other

Table 6. Average yield estimates and risk perceptions of different tillage practices

| Tillage | Crop(s) | Estimated yield[1] | Range[2] | | Risk rating[3] |
|---|---|---|---|---|---|
| Fall moldboard[4] | Continuous corn | 130.3 | +19.6 | -16.8 | 5.3 |
| Straight row[9] | Corn/ | 131.3 | +17.9 | -17.7 | 5.8 |
| | soybeans | 42.6 | + 7.8 | - 6.4 | |
| Fall chisel[5] | Continuous corn | 128.1 | +15.5 | -17.7 | 4.6 |
| Straight row | Corn/ | 129.7 | +17.9 | -17.5 | 5.3 |
| | soybeans | 41.8 | + 7.1 | - 6.4 | |
| Spring chisel[6] | Continuous corn | 122.1 | +13.8 | -15.8 | 5.8 |
| Straight row | Corn/ | 123.4 | +14.1 | -15.4 | 5.8 |
| | soybeans | 39.5 | + 6.2 | - 6.3 | |
| Spring disk[7] | Continuous corn | 123.5 | +13.8 | -15.0 | 4.8 |
| Straight row | Corn/ | 124.8 | +13.1 | -16.0 | 4.8 |
| | soybeans | 40.0 | + 6.5 | - 5.3 | |
| Fall moldboard | Continuous corn | 130.3 | +14.3 | -14.7 | 4.7 |
| Contour[10] | Corn/ | 131.7 | +15.4 | -13.8 | 4.6 |
| | soybeans | 41.8 | + 7.0 | - 5.1 | |
| Fall chisel | Continuous corn | 130.0 | +14.3 | -14.7 | 4.1 |
| Contour | Corn/ | 130.4 | +14.7 | -15.6 | 4.4 |
| | soybeans | 41.6 | + 6.6 | - 5.5 | |
| Spring chisel | Continuous corn | 124.9 | +14.4 | -13.5 | 5.4 |
| Contour | Corn/ | 125.9 | +13.4 | -12.6 | 5.3 |
| | soybeans | 40.4 | + 6.8 | - 5.9 | |
| Spring disk | Continuous corn | 125.0 | +14.3 | -13.8 | 4.7 |
| Contour | Corn/ | 127.6 | +15.4 | -16.5 | 4.7 |
| | soybeans | 41.2 | + 7.6 | - 5.6 | |
| No-till[8] | Continuous corn | 117.9 | +14.8 | -13.9 | 6.0 |
| | Corn/ | 122.1 | +14.6 | -15.5 | 6.3 |
| | soybeans | 36.6 | + 8.1 | - 7.1 | |

Risk rating: Less risky — More risky

1 2 3 4 5 6 7 8 9 10 11

Table 6. Continued.

[1] Estimated yield: For estimated yields, indicate the average per acre yield you would expect to have on your farm during an average or normal farm year.

[2] Yield range: The actual yield obtained during average or normal years may be more or less than the average yield you expect during normal years. To indicate the range of the average or normal year crop yield, please indicate in the "+" column of "D" how many additional bushels your yield might reasonably be above the average specified in column "C". Indicate in the "-" column of "D" how many fewer bushels your yield might be below the average amount of a normal year. The numbers you place in "+" and "-" columns need not be equal.

[3] Risk ranking: The scale at the bottom of the table runs from one to eleven. Using a number from this scale please indicate in column "E" your evaluation of the relative "riskiness" of the alternative crop rotation-tillage practice combinations. This ranking shows how risky you feel these alternatives are relative to each other on your farm.

[4] Fall moldboard: The crop ground is moldboard plowed in the fall following harvest.

[5] Fall chisel: The crop ground is chisel plowed in the fall following harvest.

[6] Spring chisel: The crop ground is chisel plowed in the spring before planting time.

[7] Spring disk: No moldboard or chisel plow is used. A disk is used as primary tillage in the spring.

[8] No-till: A no-till planter is used. It is assumed that planting is done on the contour with a no-till planter. There is no tillage of the soil prior to planting.

[9] Straight row: Planting is done in typical or straight fashion. No effort is made to follow the lay of the land.

[10] Contour: Planting is done to follow the lay or "contour" of the land. In determining yield estimates for contour planting, consider losses due to point rows, additional turning, etc.

hazards associated with straight-row planting.

The third section collected yield information for a corn-corn-oats-meadow-meadow rotation. A corn-corn-oats-meadow-meadow rotation may be dictated by livestock forage and bedding requirements or by erosion hazards, which prevent the use of a continuous corn or corn-soybean rotation. The yield data in Table 7 indicate that improved tilth and nitrogen carryover from the meadow raise expected corn yields above those from a corn-soybean rotation (Table 6).

Table 7. Corn-corn-oats-meadow-meadow yield estimates of Four Mile Creek farmers

| Crop | Units | Estimated yield | Yield range | |
|---|---|---|---|---|
| Corn following one-year meadow | bu. | 136.8 | + 31 | -26 |
| Corn following two-year meadow | bu. | 140.0 | + 16 | -14 |
| Oats after corn: oats | bu. | 75.0 | + 11 | -15 |
| straw | tons | 1.4 | | |
| First-year meadow | tons | 4.1 | +.8 | -.6 |
| Second-year meadow | tons | 4.2 | +.9 | -.7 |

Little information has been available on the yield impacts of terracing. Most Four Mile Creek farmers perceived that terracing decreased crop yields on their farms (Table 8). The impact of terracing on yields depends on the soil type and slope. The question was designed to consider only soils suitable for terracing.

Table 8. Average perceived yield changes from terracing reported by Four Mile Creek farmers

| Crop | Yield change |
|---|---|
| Continuous corn | -7.4 bu. |
| Corn after soybeans | -4.2 bu. |
| Soybeans after corn | -3.2 bu. |

Operators were asked to indicate expected crop prices and a normal range for these prices. The responses, summarized in Table 9, were quite similar to the prices at the time of the survey. The ranges of crop prices were pessimistic; possible decreases in the price were nearly twice as large as the possible increases.

Table 9. Expected crop price estimates reported by Four Mile Creek farmers

| Grain | Price | Price range | |
|---|---|---|---|
| | dollars per bushel | | |
| Corn | $2.37 | +.21 | -.41 |
| Soybeans | $6.13 | +.56 | -.98 |
| Oats | $1.45 | +.15 | -.23 |

## E. Livestock Management Practices

This section identified major livestock operations in the Four Mile Creek Watershed and examined aspects of livestock management that may significantly affect soil loss and water quality. Requirements of the different livestock enterprises influence the crop mix and number of pastured acres in the area. Constraints on livestock numbers limit farmer response to some erosion control policies and may alter the expected change in net income. The scale of livestock activities affects feed requirements. Grazing practices influence tillage practice choices. The removal of residue by grazing may increase soil loss.

Thirty of the 48 respondents had livestock enterprises. Table 10 shows the number of farmers engaged in each livestock activity, the average size of that activity, and the total units for all respondents.

Table 10. Livestock activities in Four Mile Creek

| Livestock activity | No. of farmers | Average size | Total units | Unit type |
|---|---|---|---|---|
| Farrow-to-finish (swine) | 14 | 78 | 1092 | litters |
| Farrow-to-feeder (swine) | 1 | 700 | 700 | head |
| Feeder-to-finish (swine) | 8 | 612 | 4290 | head |
| Beef cow/calf | 13 | 52 | 682 | head |
| Feeder calves | 5 | 105 | 527 | head |
| Finished steers | 14 | 302 | 3935 | head |
| Dairy cows | 2 | 26 | 53 | head |

Livestock enterprises, requiring pasture, meadow, or oats may reduce erosion when grass crops are substituted for row crops. Yet other livestock activities, such as swine and fed cattle, may increase corn (row crop) requirements. Table 11 presents the data collected on grass crops grown for livestock use in the Four Mile Creek Watershed. It was not possible to develop a similar estimate for row crops.

Table 11. Grass crops grown for livestock activities by Four Mile Creek farmers

| Livestock activity | Pasture |  | Meadow |  | Oats |  |
|---|---|---|---|---|---|---|
|  | Acres /farm | Total acres | Acres /farm | Total acres | Acres /farm | Total acres |
| Farrow-to-finish (swine) | 1 | 14 |  |  | 5 | 70 |
| Farrow-to-feeder (swine) |  |  |  |  | 20 | 20 |
| Feeder-to-finish (swine) |  |  |  |  | 12 | 100 |
| Beef cow/calf | 56 | 733 | 25 | 333 | 10 | 133 |
| Feeder calves | 5 | 25 | 10 | 50 | 10 | 50 |
| Finished steers | 13 | 171 | 13 | 171 | 8 | 102 |
| Dairy cows | 17.5 | 35 |  |  |  |  |
| Total |  | 978 |  | 554 |  | 475 |

To establish restraints on livestock activities in a farm model, farmers were asked to indicate what they considered minimum and maximum levels of livestock activities. For each livestock activity, Table 12 presents the minimum and maximum levels provided by the respondents.

Table 12. Limitations on livestock numbers in Four Mile Creek livestock activity

| Livestock activity | Minimum level total | Maximum level total |
|---|---|---|
| Farrow-to-finish (swine) | 212 | 1585 |
| Farrow-to-feeder (swine) | 700 | - |
| Feeder-to-finish (swine) | 1900 | 8000 |
| Beef cow/calf | 465 | 760 |
| Feeder calves | 270 | 1175 |
| Finished steers | 2030 | 4303 |
| Dairy cows | 50 | 60 |

Compared to current levels in Table 10, the two enterprises most likely to utilize increased forage crop production, beef and dairy cows, were already operating near perceived maximum levels. Only through a change in steer finishing rations could a significantly larger amount of forage crops be absorbed in the study area.

Farmers were also asked to indicate expected prices for livestock products. The average responses for expected prices are shown in Table 13. These responses were obtained for use in the linear programming analysis.

Table 13. Livestock price expectations reported by Four Mile Creek farmers

| Livestock type | Price | Price range | |
|---|---|---|---|
| | - - - - - -dollars per hundred weight - - - - - - | | |
| Finished cattle | $65.67 | +7.00 | -2.90 |
| Market hogs | $39.44 | +3.67 | -2.73 |
| Feeder pigs | $34.00 | +5.00 | -1.67 |
| Calves | $87.86 | +11.43 | -12.14 |
| Feeder cattle | $76.43 | +8.43 | -7.71 |
| Milk | $12.00 | +0.75 | -0.00 |

## F. Risk Attitudes

Part IV of the Four Mile Creek survey was directed at the risk attitudes of Four Mile Creek farmers and the behavior of farm operators in risky situations. These data can be used to classify farmers, over specified income ranges, as risk averse, risk neutral, or risk taking. These risk classifications of farmers are utilized in the econometric analysis of conservation tillage adoption.

To determine risk preference, the respondent is presented two alternative incomes which may be obtained as a consequence of a decision. One income is greater than the other and each has an equal probability of occurring. The farmers is then asked to select a certain income level such that he would be indifferent relative to the risky choice. If this certain income selected is less than the expected value of the choice, then the individual is risk averse. If this certain income is in excess of the expected value of the risky choice the individual is risk taking. Finally, if the certain income is equal to the expected value of the risky choice, the individual is risk neutral. This experiment is repeated for a range of income situations. The pattern of response suggests that the majority of Four Mile Creek farmers are risk neutral to slightly risk averse. Figure 1 summarizes the responses.

## G. Miscellaneous Farm Questions

Additional background information was collected. These data will facilitate the farm modeling effort. For example, data on additional time required to perform field operations on contoured or terraced land can be used to increase the labor and fuel costs for contour and terrace farming operations in the watershed models. The estimates for the increased time required to farm on the contour was 9.7 percent. The estimate for additional farming time on terraces was 12.7 percent.

## H. Land Mapping

The 1980 soil survey of the Four Mile Creek Watershed was used to establish the soil types found in the area. The watershed was divided into 40-acre plots and the total acreage of each soil type in the plots was tabulated. Yield and erosion factors for each soil type in the plots were tabulated. Plot data are mapped in Figures 2 and 3.

For data collection purposes, the Four Mile Creek Watershed was divided into five subwatersheds by the Agricultural Engineering Department. The plots were aggregated to coincide with these subregions. The effectiveness of soil erosion control practices could

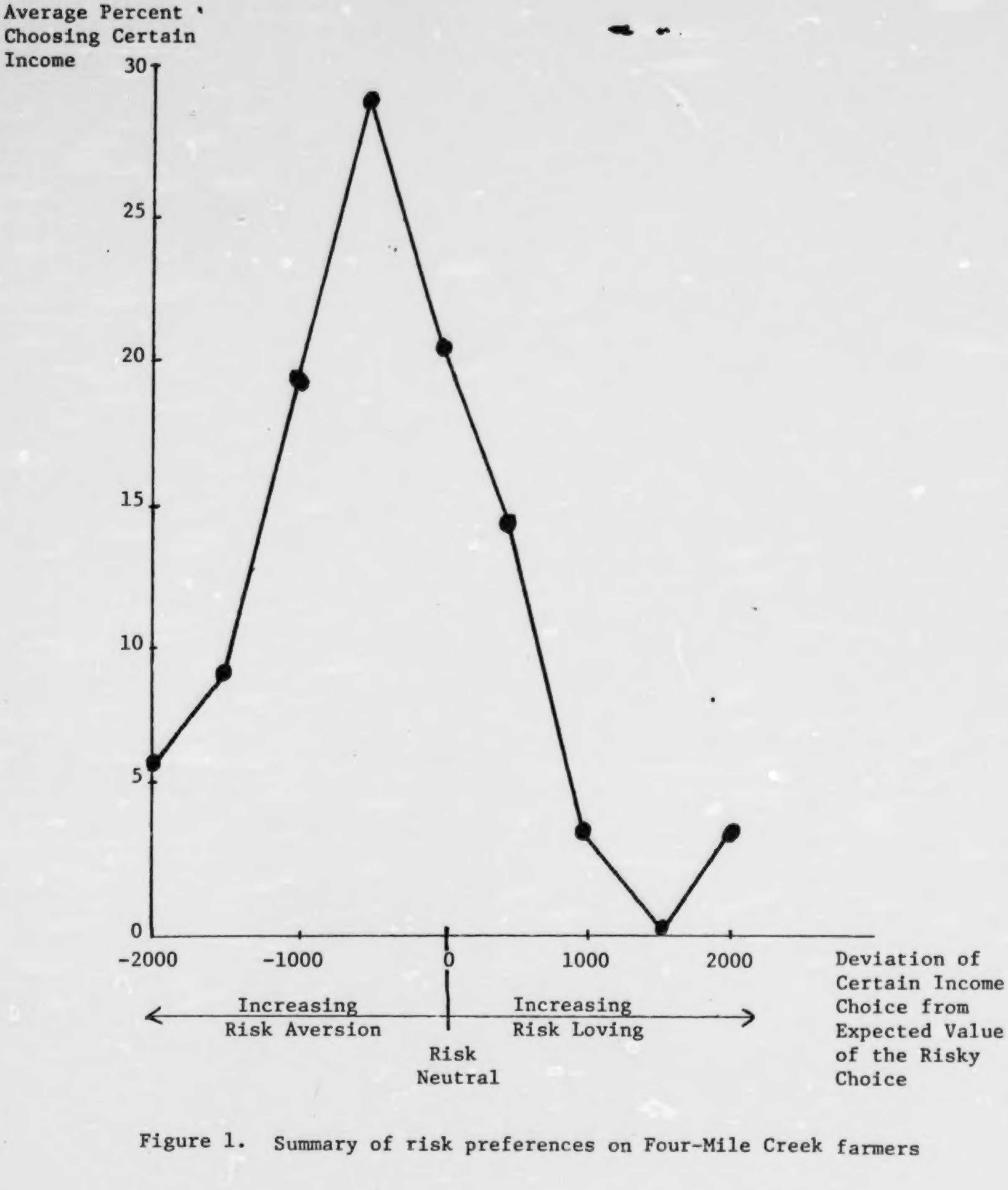
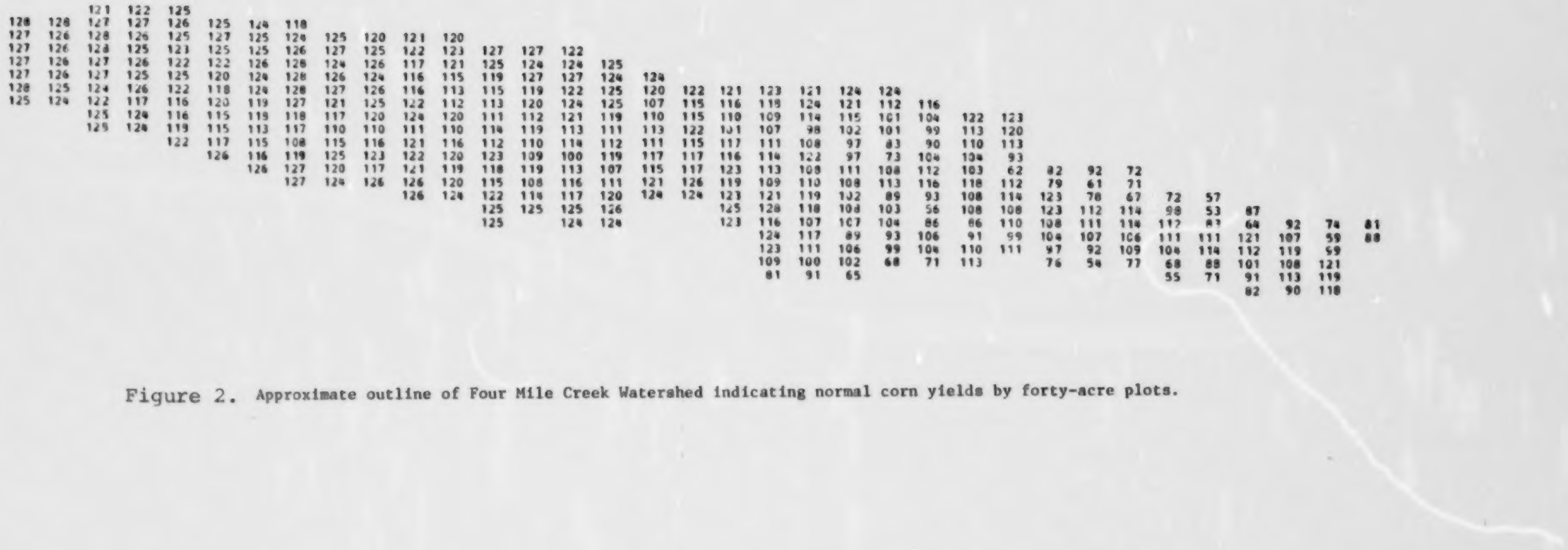


Figure 1. Summary of risk preferences on Four-Mile Creek farmers



|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | 121 | 122 | 125 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 128 | 128 | 127 | 127 | 126 | 125 | 124 | 118 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 127 | 126 | 128 | 126 | 125 | 127 | 125 | 124 | 125 | 120 | 121 | 120 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 127 | 126 | 128 | 125 | 123 | 125 | 125 | 126 | 127 | 125 | 122 | 123 | 127 | 127 | 122 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 127 | 126 | 127 | 126 | 122 | 122 | 126 | 128 | 124 | 126 | 117 | 121 | 125 | 124 | 124 | 125 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 127 | 126 | 127 | 125 | 125 | 120 | 124 | 128 | 126 | 124 | 116 | 115 | 119 | 127 | 127 | 124 | 124 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 128 | 125 | 124 | 126 | 122 | 118 | 124 | 128 | 127 | 126 | 116 | 113 | 115 | 119 | 122 | 125 | 120 | 122 | 121 | 123 | 121 | 124 | 124 |  |  |  |  |  |  |  |  |  |  |  |  |
| 125 | 124 | 122 | 117 | 116 | 120 | 119 | 127 | 121 | 125 | 122 | 112 | 113 | 120 | 124 | 125 | 107 | 115 | 116 | 119 | 124 | 121 | 112 | 116 |  |  |  |  |  |  |  |  |  |  |  |
|  |  | 125 | 124 | 116 | 115 | 119 | 118 | 117 | 120 | 124 | 120 | 111 | 112 | 121 | 119 | 110 | 115 | 110 | 109 | 114 | 115 | 101 | 104 | 122 | 123 |  |  |  |  |  |  |  |  |  |
|  |  | 125 | 124 | 119 | 115 | 113 | 117 | 110 | 110 | 111 | 110 | 114 | 119 | 113 | 111 | 113 | 122 | 101 | 107 | 98 | 102 | 101 | 99 | 113 | 120 |  |  |  |  |  |  |  |  |  |
|  |  |  |  | 122 | 117 | 115 | 108 | 115 | 116 | 121 | 116 | 112 | 110 | 114 | 112 | 111 | 115 | 117 | 111 | 108 | 97 | 83 | 90 | 110 | 113 |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  | 126 | 116 | 119 | 125 | 123 | 122 | 120 | 123 | 109 | 100 | 119 | 117 | 117 | 116 | 114 | 122 | 97 | 73 | 104 | 104 | 93 |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | 126 | 127 | 120 | 117 | 121 | 119 | 118 | 119 | 113 | 107 | 115 | 117 | 123 | 113 | 108 | 111 | 108 | 112 | 103 | 62 | 82 | 92 | 72 |  |  |  |  |  |  |
|  |  |  |  |  |  |  | 127 | 124 | 126 | 126 | 120 | 115 | 108 | 116 | 111 | 121 | 126 | 119 | 109 | 110 | 108 | 113 | 116 | 118 | 112 | 79 | 61 | 71 |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  | 126 | 124 | 122 | 114 | 117 | 120 | 124 | 124 | 123 | 121 | 119 | 102 | 89 | 93 | 108 | 114 | 123 | 78 | 67 | 72 | 57 |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  | 125 | 125 | 125 | 126 |  |  | 125 | 128 | 118 | 108 | 103 | 56 | 108 | 108 | 123 | 112 | 114 | 98 | 53 | 87 |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  | 125 |  | 124 | 124 |  |  | 123 | 116 | 107 | 107 | 104 | 86 | 86 | 110 | 108 | 111 | 114 | 112 | 87 | 64 | 92 | 74 | 81 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 124 | 117 | 89 | 93 | 106 | 91 | 99 | 104 | 107 | 106 | 111 | 111 | 121 | 107 | 59 | 88 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 123 | 111 | 106 | 99 | 104 | 110 | 111 | 97 | 92 | 109 | 104 | 114 | 112 | 119 | 59 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 109 | 100 | 102 | 68 | 71 | 113 |  | 76 | 54 | 77 | 68 | 88 | 101 | 108 | 121 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 81 | 91 | 65 |  |  |  |  |  |  |  | 55 | 71 | 91 | 113 | 119 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 82 | 90 | 118 |  |

Figure 2. Approximate outline of Four Mile Creek Watershed indicating normal corn yields by forty-acre plots.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | 40 | 37 | 29 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 10 | 6 | 13 | 17 | 17 | 37 | 32 | 48 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 10 | 1 | 3 | 8 | 17 | 13 | 23 | 32 | 25 | 48 | 54 | 45 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 14 | 11 | 4 | 10 | 12 | 19 | 17 | 17 | 14 | 28 | 42 | 41 | 19 | 15 | 34 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 18 | 12 | 8 | 17 | 25 | 24 | 14 | 1 | 41 | 40 | 55 | 42 | 26 | 38 | 35 | 50 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 15 | 10 | 13 | 14 | 19 | 44 | 18 | 7 | 17 | 50 | 55 | 56 | 58 | 30 | 31 | 28 | 13 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 6 | 21 | 38 | 20 | 23 | 54 | 25 | 6 | 22 | 47 | 33 | 61 | 50 | 53 | 49 | 18 | 44 | 56 | 68 | 65 | 69 | 47 | 52 |  |  |  |  |  |  |  |  |  |  |  |  |
| 15 | 17 | 34 | 58 | 62 | 47 | 45 | 16 | 40 | 41 | 56 | 101 | 56 | 58 | 54 | 28 | 109 | 74 | 111 | 80 | 90 | 68 | 86 | 62 |  |  |  |  |  |  |  |  |  |  |  |
| 18 | 5 | 13 | 30 | 68 | 59 | 58 | 58 | 62 | 66 | 70 | 77 | 80 | 73 | 56 | 53 | 88 | 86 | 122 | 91 | 96 | 79 | 138 | 123 | 42 | 38 |  |  |  |  |  |  |  |  |  |
| 40 | 20 | 1 | 27 | 59 | 69 | 26 | 32 | 41 | 30 | 38 | 55 | 24 | 55 | 86 | 103 | 68 | 66 | 144 | 123 | 136 | 138 | 183 | 105 | 99 | 54 |  |  |  |  |  |  |  |  |  |
|  |  |  |  | 43 | 68 | 63 | 95 | 71 | 74 | 48 | 86 | 79 | 51 | 46 | 35 | 29 | 39 | 44 | 94 | 74 | 156 | 255 | 165 | 121 | 112 |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  | 18 | 70 | 75 | 26 | 43 | 55 | 51 | 65 | 97 | 125 | 29 | 80 | 83 | 37 | 30 | 33 | 114 | 209 | 119 | 134 | 145 |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  | 11 | 15 | 35 | 72 | 60 | 54 | 28 | 50 | 114 | 84 | 91 | 115 | 58 | 94 | 60 | 30 | 10 | 12 | 114 | 182 | 150 | 174 | 176 |  |  |  |  |  |  |
|  |  |  |  |  |  |  | 16 | 16 | 33 | 33 | 83 | 79 | 77 | 26 | 35 | 70 | 48 | 66 | 104 | 56 | 84 | 57 | 44 | 19 | 92 | 153 | 191 | 179 |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  | 26 | 39 | 54 | 90 | 83 | 84 | 58 | 61 | 47 | 55 | 60 | 113 | 131 | 121 | 55 | 10 | 61 | 209 | 207 | 206 | 196 |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  | 26 |  | 28 | 44 |  |  | 36 | 39 | 71 | 102 | 140 | 238 | 102 | 5 | 30 | 56 | 79 | 155 | 220 | 139 |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 56 | 92 | 98 | 72 | 98 | 118 | 218 | 88 | 10 | 13 | 59 | 55 | 110 | 181 | 128 | 154 | 157 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 45 | 94 | 172 | 113 | 63 | 99 | 91 | 98 | 51 | 7 | 23 | 50 | 63 | 90 | 204 | 194 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 58 | 112 | 78 | 107 | 116 | 95 | 88 | 154 | 105 | 87 | 58 | 5 | 53 | 60 | 126 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 101 | 139 | 108 |  |  | 97 |  | 161 | 227 | 183 | 263 | 146 | 49 | 22 | 30 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 245 | 236 | 190 | 56 | 25 |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 204 | 177 | 87 |  |

Figure 3. Approximate outline of Four Mile Creek Watershed indicating average RKLS1 by forty-acre plots.

be evaluated on these three levels of aggregation--40 acre plots, 5 subwatersheds, or the entire watershed. Time limited our evaluation to the 5 subwatersheds and the entire watershed. However, further analysis could be undertaken to determine the effects of scaling-up (aggregation) on the results. As the level of disaggregation increases, more of the micro data collected in the survey could be applied. Fortunately, the plots coincided with farm operator boundaries so that only 5 of nearly 320 plots had more than one operator. Section III of this report illustrates one potential use of the soil mapping data.

Figure 2 maps corn yield potential for the plots in the watershed and illustrates the corn yield potential of the alternative plots or management units. The average RKLS1 factors for the 40 acre management units (Figure 3) indicates the erosion potential of various areas in the watershed as well as the potential plots for targeting erosion control practices for water quality improvement.

## III. BMP Cost-Effectiveness Evaluation Framework

The focus of this section is a preliminary assessment of the cost-effectiveness of management practices designed to reduce soil erosion and to improve water quality. Additionally, the analytical framework lends itself to the evaluation of scaling-up impacts when going from field to farm, farm to subwatershed, and subwatershed to watershed levels of management implementation. This latter capability will be illustrated but not emphasized in the discussion.

The cost-effectiveness of alternative soil erosion control practices is evaluated in an activity analysis framework. The term activity analysis is used in a broader sense in this report than that generally used in the economics literature. Herein, activity analysis is defined as the procedure by which impact estimates are made with respect to soil loss (residual) control and to soil loss control costs. Such a model can vary from a simple accounting analysis of residuals control impacts and costs, to a more complex linear programming model, which selects among alternative activities so as to maximize a particular objective function subject to specific resource constraints. Our activity analysis model is more of the accounting variety than of the linear programming type.

An earlier cost-effectiveness study was undertaken at Cornell University.* Although this study attempted to assess the cost-effectiveness of BMP's for soil erosion control, it differed in three major respects from our efforts. First, the Cornell study employed a more complex activity analysis framework, using a representative farm linear programming model. Second, the Cornell study relied on secondary data sources to derive the coefficients for the representative farms. Third, the model lacked any facility for scaling-up to a higher level of aggregation.

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*Smith, Erick E., Earl A. Lang, George L. Casler, and Roger W. Hexem. "The Cost Effectiveness of Soil and Water Conservation Practices for Improvement of Water Quality," Section 8 from Effectiveness of Soil and Water Conservation Practices for Pollution Control. EPA-600/3-79-106, October 1979.

The results in our analysis are based on actual responses of farmers to the Four Mile Creek Watershed survey (see Section II), on conservation structure (terraces and contours) cost data provided by the SCS in Tama County, Iowa, and on the Soil Survey for the county. Because our units of observation are forty-acre parcels (almost synonymous with fields), we can scale-up from the "field" to the watershed level. Such data are particularly useful in targeting practices to achieve the "least cost" solution for water quality improvements.

For each erosion control activity or group of activities, a coefficient depicting the contribution of that activity to the reduction in soil loss, given a specific soil resource situation, is required. Likewise, a coefficient is needed to reflect the practice and opportunity cost associated with this particular activity or group of activities. Thus, if we know what activity is initiated, the activity level (both with respect to type and acres of land involved), the associated cost, and the impact on soil loss, we can derive the cost-effectiveness of that activity. For example, if we impose the requirement that cropland with slope greater than 9 percent must be terraced and assuming that we know the number of acres of cropland which has slope exceeding the prescribed level, then applying the soil loss reduction coefficients and the cost coefficients, we can derive the cost-effectiveness of that regulation.

To develop an activity analysis model of the type described herein, certain data and assumptions are required. These inputs into the activity analysis model include:

1. Assume that soils with slopes >14 percent are pastured. Yield data from the soil survey indicates that row crop activities on these soils are unprofitable.
2. Structure (i.e., terrace and contour) costs are based on estimates provided by the Tama County Soil Conservation Service personnel. These costs are annualized to reflect soil erosion control benefits over a 20-year life of the structures.
3. Opportunity costs include perceived tillage costs and yield penalties summarized from the Four-Mile Creek survey. Fuel and labor costs are adjusted to account for the increased time requirements associated with terracing and contouring as perceived by the survey respondents. Generally, no yield penalty was associated with contouring, but farmers did perceive a yield penalty with terracing (see Section II).
4. Erosion estimates generated in the activity model are based on a C factor of 0.30. This factor pertains to a corn-corn-

soybean rotation with fall chisel tillage, which is the predominate row-crop mix and tillage practice in the area.

5. Complete utilization of the particular erosion control practice occurs in the activity model. The effectiveness of less than 100 percent practice utilization can be determined by a linear interpolation between the specific solution and the baseline. Results for combinations of practices may be obtained in a similar manner. Results for tillage practice alternatives could be developed by appropriately modifying the C factors and costs.

The results in Table 14 are based on the imposition of individual erosion control practices in the Four-Mile Creek Watershed. The activity analysis model was used to calculate the average soil loss per acre in the watershed, the average cost per ton of reduction, and the marginal cost per ton of reduction under each of the practices imposed. As the results indicate, substantial reductions in soil loss are possible at relatively modest cost per ton if contour cultivation is imposed on slopes exceeding 2 percent. Contouring has the lowest cost per ton of reduction, but its effectiveness is limited to reducing soil loss to 9 tons per acre. To achieve a comparable level of control with either terracing or pasturing more steeply sloped land, significantly higher costs will be incurred. Pasturing all slopes greater than 5 percent could reduce average soil loss to 3 tons per acre, but the cost of this practice would be extremely high. Yet to achieve socially desired levels of soil erosion control, contouring

Table 14. Impact and Cost of Alternative Erosion Control Practices in the Four-Mile Creek Watershed

| | Baseline | Terrace SL>2%* | Terrace SL>5% | Terrace SL>9% | Contour SL>2% | Contour SL>5% | Contour SL>9% | Pasture SL>5% | Pasture SL>9% |
|---|---|---|---|---|---|---|---|---|---|
| Total soil loss (tons) | 203189 | 72166 | 90860 | 154193 | 115633 | 132023 | 173443 | 34873 | 126916 |
| Average soil loss per acre (tons) | 17 | 6 | 7 | 12 | 9 | 11 | 14 | 3 | 10 |
| Straight row acres | 11689 | 1717 | 7028 | 10342 | 1717 | 7029 | 10342 | 7029 | 10342 |
| Pasture acres | 601 | 601 | 601 | 601 | 601 | 601 | 601 | 5269 | 1956 |
| Terraced acres | 0 | 9981 | 4669 | 1356 | 0 | 0 | 0 | 0 | 0 |
| Contoured acres | 0 | 0 | 0 | 0 | 9981 | 4669 | 1356 | 0 | 0 |
| Structure cost ($) | 0 | 18843 | 9175 | 3145 | 1098 | 514 | 149 | 0 | 0 |
| Opportunity cost ($) | 0 | 183256 | 81755 | 22182 | 13450 | 6544 | 2237 | 600203 | 148606 |
| Total cost ($) | 0 | 202099 | 90931 | 25327 | 14547 | 7058 | 2386 | 600203 | 148606 |
| Average cost per ton reduced ($) | | 1.54 | .81 | .52 | .17 | .10 | .08 | 3.56 | 1.95 |
| Marginal cost per ton reduced ($) | | 5.95 | .96 | .52 | .46 | .11 | .08 | 4.91 | 1.95 |

*SL>2% is when the practice is applied to all slopes (SL) greater than two percent in the watershed.

may not be sufficient. Thus some combination of practices may be required, and terracing is the next "least costly" step. It should be noted that neither terracing nor contouring alone is sufficient to reduce soil loss to 5 tons per acre per year.

As expected the marginal cost of control increases substantially as soil loss is decreased regardless of the practice imposed. Under some circumstances, a combination of practices may be less costly than individual practices, but that is not the case in this illustration. If tillage practices were introduced into this illustration, then it is highly probable that some combination of reduced tillage and contouring would be more cost-effective relative to either practice alone. Future extensions of the analysis will incorporate tiliage alternatives.

As illustrated in Table 15, the effectiveness of the practices varies in each subwatershed. The average gross soil loss per acre in subwatershed 1 is 5 tons per acre, considerably less than the other subwatersheds. The average cost to reduce soil loss is considerably higher in this watershed using any of the erosion control practice, Targeting subsidies or regulations to problem areas, will cause a greater reduction in soil loss per dollar than making a subsidy available to or imposing regulations on the entire watershed.

Although Table 15 does not provide a direct estimate of the impacts of selective imposition of practices on more than one subwatershed, these impacts can be derived by adding the appropriate subwatershed results. For example, to determine the total effects of

Table 15. Cost-Effectiveness of Different Erosion Control Practices by Subwatershed in the Four-Mile Creek Watershed

| | BASELINE | TERRACE SL>2% | TERRACE SL>5% | TERRACE SL>9% | CONTOUR SL>2% | CONTOUR SL>5% | CONTOUR SL>9% | PASTURE SL>5% | PASTURE SL>9% |
|---|---|---|---|---|---|---|---|---|---|
| TOTAL SOIL LOSS | 203189 | 72166 | 93860 | 154193 | 115633 | 132023 | 173443 | 34873 | 126216 |
| WATERSHED1 | 3765 | 1465 | 3009 | 3765 | 2018 | 3270 | 3765 | 2664 | 3765 |
| WATERSHED2 | 125950 | 45080 | 58117 | 100885 | 71774 | 83115 | 111127 | 24131 | 86380 |
| WATERSHED3 | 8383 | 2987 | 3425 | 5458 | 4866 | 5276 | 6609 | 873 | 3934 |
| WATERSHED4 | 21141 | 7492 | 9695 | 13947 | 12250 | 13358 | 16783 | 2356 | 9368 |
| WATERSHED5 | 42942 | 15139 | 17608 | 30132 | 24720 | 26998 | 35152 | 4847 | 22956 |
| AVG SOIL LOSS/ acre | 17 | 6 | 7 | 12 | 9 | 11 | 14 | 3 | 10 |
| WATERSHED1 | 5 | 2 | 4 | 5 | 3 | 5 | 5 | 4 | 5 |
| WATERSHED2 | 16 | 6 | 7 | 13 | 9 | 11 | 14 | 3 | 11 |
| WATERSHED3 | 26 | 9 | 10 | 17 | 15 | 16 | 20 | 3 | 12 |
| WATERSHED4 | 23 | 9 | 9 | 15 | 14 | 15 | 19 | 3 | 11 |
| WATERSHED5 | 16 | 6 | 6 | 11 | 9 | 10 | 13 | 2 | 9 |
| STRAIGHT ROW acres | 11698 | 1717 | 7028 | 10342 | 1717 | 7029 | 10342 | 7029 | 10342 |
| WATERSHED1 | 689 | 266 | 649 | 689 | 266 | 649 | 689 | 649 | 689 |
| WATERSHED2 | 7571 | 976 | 4633 | 6874 | 976 | 4634 | 6874 | 4634 | 6874 |
| WATERSHED3 | 324 | 1 | 140 | 247 | 1 | 140 | 247 | 140 | 247 |
| WATERSHED4 | 856 | 2 | 372 | 651 | 2 | 373 | 651 | 373 | 651 |
| WATERSHED5 | 2257 | 472 | 1232 | 1881 | 472 | 1233 | 1881 | 1223 | 1881 |
| PASTURE | 601 | 601 | 601 | 601 | 601 | 601 | 601 | 5269 | 1936 |
| WATERSHED1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 40 | 0 |
| WATERSHED2 | 133 | 133 | 133 | 133 | 133 | 133 | 133 | 3070 | 8307 |
| WATERSHED3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 194 | 77 |
| WATERSHED4 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 593 | 250 |
| WATERSHED5 | 422 | 422 | 422 | 422 | 422 | 422 | 422 | 1446 | 798 |
| TERRACED ACRES | 0 | 9981 | 4669 | 1356 | 0 | 0 | 0 | 0 | 0 |
| WATERSHED1 | 0 | 423 | 39 | 0 | 0 | 0 | 0 | 0 | 0 |
| WATERSHED2 | 0 | 6595 | 2937 | 697 | 0 | 0 | 0 | 0 | 0 |
| WATERSHED3 | 0 | 323 | 184 | 77 | 0 | 0 | 0 | 0 | 0 |
| WATERSHED4 | 0 | 854 | 482 | 204 | 0 | 0 | 0 | 0 | 0 |
| WATERSHED5 | 0 | 1785 | 1024 | 376 | 0 | 0 | 0 | 0 | 0 |
| CONTOURED ACRES | 0 | 0 | 0 | 0 | 9981 | 4669 | 1356 | 0 | 0 |
| WATERSHED1 | 0 | 0 | 0 | 0 | 423 | 40 | 0 | 0 | 0 |
| WATERSHED2 | 0 | 0 | 0 | 0 | 6595 | 2938 | 697 | 0 | 0 |
| WATERSHED3 | 0 | 0 | 0 | 0 | 323 | 184 | 77 | 0 | 0 |
| WATERSHED4 | 0 | 0 | 0 | 0 | 854 | 483 | 204 | 0 | 0 |
| WATERSHED5 | 0 | 0 | 0 | 0 | 1785 | 1025 | 376 | 0 | 0 |
| STRUCTURE COST | 0 | 18843 | 9175 | 3145 | 1098 | 514 | 149 | 0 | 0 |
| WATERSHED1 | 0 | 770 | 72 | 0 | 47 | 4 | 0 | 0 | 0 |
| WATERSHED2 | 0 | 12352 | 5695 | 1618 | 725 | 323 | 77 | 0 | 0 |
| WATERSHED3 | 0 | 627 | 373 | 179 | 36 | 20 | 9 | 0 | 0 |
| WATERSHED4 | 0 | 1656 | 981 | 474 | 94 | 53 | 22 | 0 | 0 |
| WATERSHED5 | 0 | 3438 | 2053 | 873 | 196 | 113 | 41 | 0 | 0 |
| OPPORTUNITY cost | 0 | 183256 | 81755 | 22182 | 13450 | 6544 | 2237 | 600203 | 148606 |
| WATERSHED1 | 0 | 8263 | 725 | 0 | 550 | 52 | 0 | 5556 | 0 |
| WATERSHED2 | 0 | 122086 | 51955 | 11456 | 9818 | 4063 | 1151 | 385113 | 77149 |
| WATERSHED3 | 0 | 5963 | 3276 | 1325 | 447 | 266 | 128 | 24184 | 9249 |
| WATERSHED4 | 0 | 15236 | 8290 | 3316 | 1182 | 699 | 337 | 59529 | 21981 |
| WATERSHED5 | 0 | 31703 | 17503 | 6073 | 2453 | 1464 | 621 | 125803 | 40217 |
| TOTAL COST | 0 | 202099 | 90931 | 25327 | 14547 | 7058 | 2386 | 600203 | 148606 |
| WATERSHED1 | 0 | 9033 | 798 | 0 | 597 | 56 | 0 | 5556 | 0 |
| WATERSHED2 | 0 | 134438 | 57651 | 13084 | 9543 | 4386 | 1227 | 385113 | 77149 |
| WATERSHED3 | 0 | 6590 | 3649 | 1505 | 483 | 287 | 136 | 24184 | 9249 |
| WATERSHED4 | 0 | 16892 | 9271 | 3790 | 1275 | 752 | 360 | 59529 | 21981 |
| WATERSHED5 | 0 | 35141 | 19557 | 6946 | 2649 | 1577 | 662 | 125803 | 40217 |
| AVG. COST/ ton reduced | | 1.54 | .81 | .52 | .17 | .10 | .08 | 3.56 | 1.95 |
| WATERSHED1 | | 3.93 | 1.05 | - | .34 | .11 | .08 | 5.05 | - |
| WATERSHED2 | | 1.64 | .84 | .50 | .17 | .10 | .08 | 3.75 | 1.90 |
| WATERSHED3 | | 1.22 | .74 | .51 | .14 | .10 | .08 | 3.22 | 2.03 |
| WATERSHED4 | | 1.24 | .74 | .53 | .14 | .10 | .08 | 3.17 | 1.97 |
| WATERSHED5 | | 1.26 | .77 | .54 | .14 | .10 | .08 | 3.30 | 2.01 |
| MARGINAL COST/ton | | 5.95 | .96 | .52 | .46 | .11 | .08 | 4.91 | 1.95 |
| WATERSHED1 | | 5.33 | 1.05 | - | .43 | .11 | - | 5.05 | - |
| WATERSHED2 | | 5.89 | 1.04 | .50 | .45 | .11 | .08 | 4.91 | 1.40 |
| WATERSHED3 | | 6.73 | 1.06 | .51 | .49 | .11 | .08 | 5.04 | 2.03 |
| WATERSHED4 | | 6.32 | 1.04 | .53 | .47 | .11 | .08 | 4.93 | 1.97 |
| WATERSHED5 | | 6.31 | 1.01 | .54 | .47 | .11 | .08 | 4.72 | 2.01 |

terracing in only subwatersheds 2 and 5, the results for these watersheds can be added to obtain the total impact. The average impacts can be obtained by dividing the total impact by the acres or by tons reduced.

The analysis can be scaled down to a field-by-field basis using the yield and RKLS data developed for the 40 acre plots. Smaller units may be targeted for practice subsidies, further increasing the cost-effectiveness of each subsidy dollar but increasing the information, administration, and enforcement costs. Knowledge of sediment delivery from each of these smaller plots may reveal that water quality may be improved considerably by controlling erosion from a small number of acres, or by installing delivery inhibiting structures in selected areas. This disaggregation may be more realistic than the management of each soil type in a more aggregate model for a watershed.

Given the nature of the data available and the analytical framework developed, the Four-Mile Creek Watershed provides an opportunity for a unique evaluation of the impacts of aggregation. Once a policymaker specifies the standard or level of soil loss control required, the results of the activity analysis indicate the most cost-effective practices to achieve the standard and the extent of BMP imposition required, or alternatively, the level of subsidy required to induce the adoption of sufficient practices to achieve the standard. Additionally, the watershed can be disaggregated to facilitate the targeting of practices to subwatersheds, farms, or fields to achieve a more efficient solution. In other words, the activity analysis framework permits comparisons across practices and across land units to determine the most cost-effective means of accomplishing a given reduction in soil loss. As previously indicated, such cost savings are accomplished at the expense of increased information and administration costs. Also, the political costs of targeting cannot be ignored if equity considerations favor the watershed as the logical target rather than subwatershed or farm unit.

There are some limits to this type of analysis. First, it is only an approximation to a cost-minimizing solution. Second, this framework is not capable of evaluating soil loss limits, unless substantially more detail is introduced into the model. Even then, a least-cost solution would not be readily obtainable. Finally, and perhaps the most serious limitation, the activity model is based solely on technical accounting information and ignores behavioral responses. Farmers may not respond as anticipated if factors such as risk attitudes, experience, tenure, and farm size influence their decisions. Such factors are addressed in the next section.

# IV. Adoption of Conservation Tillage Practices

## A. Introduction

The U.S. Environmental Protection Agency has shown a preference for Best Management Practices (BMP's), or on-site erosion control practices, to reduce nonpoint pollutants. To the extent that these BMP's control residual flows from the farm into receiving waters, water quality improvements should result. At the same time, the U.S. Department of Agriculture is charged with developing measures to achieve effective soil conservation as part of the 1975 Soil and Water Resources Conservation Act. It appears that the emphasis in the USDA's soil conservation policy will be on continued incentives to adopt specific erosion control practices.

One specific practice that has received considerable interest in recent years is conservation (or reduced) tillage. Yet, the incentives that will be required to induce particular farm operators to adopt conservation tillage practices are not fully identified. It is important in developing efficient, effective, and equitable soil erosion control policies that decision makers better understand the conservation tillage adoption process as well as the incentives required to induce adoption. In this section, the results of an econometric analysis of conservation tillage adoption in the Four Mile Creek Watershed of Iowa are presented. The purpose of this analysis is to provide insight into the decision to adopt conservation tillage practices and thus to develop an information base for policymakers charged with developing soil conservation policies.

## B. Comments on Adoption Decisions and Empirical Methods

The applied economic analysis of erosion control policies has generally relied upon the assumptions that farmers operate in an environment of perfect information and that they are profit maximizers. With these assumptions and data on crop production practices and returns, analysts have developed numerical models of crop and livestock production for representative farms, watersheds, river basins, crop production regions (e.g., Corn Belt), and the nation. These models have been used to determine how alternative erosion control policies will affect production variables (including the choice of practices). The results of such analyses are, however, dependent upon the assumptions utilized which may not accurately reflect farm operators' perceptions and behavior. If these assumptions are violated, the analysis becomes considerably more complex. The economic problem of adoption is viewed best as a problem of choice under conditions of uncertainty where choice is subject to a number of restrictions. Under these conditions, the appropriate conceptual mode of analysis is decision theory. The key elements of a decision model are the operator's utility function, which embodies the risk preferences of the operator, the objects of choice, the alternative states of the world perceived to exist, the probabilities attached to these states by the operator, and the restrictions on choice.

Critical in any analysis of choice under conditions of uncertainty are risk perceptions and preferences. Given data on utility functions, subject to certain restrictions, and on the perceived distributions of variables, it is possible to model economic behavior. Analyses based on detailed individual situations could be performed to ascertain the response of farmers to policy measures. Such data are not available, though, and the best that can be done with programming techniques is to model hypothetical situations. The usefulness of such models for policy formation is clearly limited.

Given the limitations encountered in modeling behavior, we have chosen to focus on the adoption decision, i.e., the problem of which practice to use. An empirical model of the farmer's decision is constructed to explain this choice and to serve as a basis for selecting policy measures. The data utilized in estimating this model were acquired in the Four Mile Creek survey discussed in Section II.

### C. The Model of Conservation Tillage Practice Adoption

Four Mile Creek farmers were asked in the survey to detail the farming practices that they would use to grow different crop rotations on hilly ground and on level ground. The rotation sequences for which they were asked to detail their practices were corn-after-soybeans, soybeans-after-corn, continuous corn, and corn-after-meadow. Based upon the survey responses, it was possible to identify the primary tillage systems which respondents would adopt. These responses offer the basis for the development of a probability model of the choice of primary tillage practices on continuous corn, soybeans-after-corn and corn-after-soybeans rotations. The analysis was limited to these three rotations because corn-after-meadow normally requires moldboard plowing.

For this analysis we do not consider the probability of a farmer choosing a particular tillage practice from the complete set of alternatives but instead focus upon the probability that a farm operator will choose one of the conservation tillage practices as opposed to moldboard plowing. A linear probability model is utilized to consider this problem and is specified as follows:

$$P_{ijh} = \beta_0 + \beta_1 \, EXP_i + \beta_2 \, ED_i + \beta_3 \, FS_i + \beta_4 \, TEN_i$$
$$+ \beta_5 \, DVJ_{ij} + \beta_6 \, DVH_{ih} + \beta_7 \, RD_i + \beta_8 \, YCD_{ij} + \varepsilon_{ijh}$$

where $P_{ijh}$ = probability that farmer i will utilize a practice other than moldboard plow on a field of type h for crop rotation j;

$EXP_i$ = years experience of farm operator i;

$ED_i$ = educational attainment of farm operator i;

$FS_i$ = size of farm managed by operator i;

$TEN_i$ = the tenure status of farm operator i;

$DVJ_{ij}$ = dummy for operator i using crop rotation j;

$DVH_{ih}$ = dummy for operator i with field type h;

$YCD_i$ = expected corn yield of practice less the expected corn yield with moldboard plow for operator i;

$RD_i$ = perceived risk of practice less perceived risk with moldboard plow for operator i;

$\varepsilon_{ijh}$ = error term.

The experience (EXP) of the farm operator is measured as the number of years as an operator, while operator education (ED) is measured by the highest grade of formal education attained. These variables are included as human capital proxies. The greater the allocative and technical abilities of the farmer, the better able the farmer is to ascertain the impact of a tillage choice on expected welfare. Then if we assume that nonmoldboard tillage increases the farmer's expected welfare, it would be expected that $\beta_1$ and $\beta_2$ are positive since experience and education generally enhance the operators stock of human capital and thus the operators managerial abilities.

Farm size (FS) is measured as the number of acres operated and farm tenure (TEN) as the ratio of acres owned and operated to the total acres operated. These are the farm structure variables included in the model. It is frequently suggested that the more tenured the operator the more "conservation minded" the operator will be. Thus it is hypothesized that $\beta_4 > 0$. It should be noted here, however, that if markets are reasonably efficient one can argue that tenure should have no impact on choice. Farm size* is a variable which can capture many factors of interest including risk spreading, capital acquisition, and scale economies which may influence choice. While farm size is expected to influence choice, the sign of the associated parameter is uncertain.

The rotational dummy variable (DVJ) is equal to one if the rotation is beans-after-corn or corn-after-beans and zero if the rotation is continuous corn. Given the slightly greater erosivity of rotations with beans and the need for less tillage on corn following beans, it is expected that $\beta_5 > 0$, indicating that the operator is more likely to choose a less erosive tillage practice for such a rotation. The field slope dummy variable (DVH) is equal to one if the choice involves "hilly" ground, and equal to zero if the choice is being made for "level" ground. Given that hilly ground will generally be more erosive than level ground, it is to be expected that $\beta_6 > 0$, again indicating the operator will be more likely to choose a tillage practice with a lesser erosion hazard if erosivity is a factor in adoption.

The risk farm operators perceive to be inherent in a tillage practice may be expected to influence adoption decisions. In measuring risk, economists have looked at attributes of the distributions of economic variables. Until the late 1960's, risk was generally measured by the variance of distributions. However, this measure is suitable if and only if the individual's utility function is quadratic or the distributions under consideration are normal. As a consequence of the unsatisfactory nature of variance as a measure of risk, economists have sought alternative measures in recent years. A number of risk proxies have been proposed, but these measures are generally

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[*] Farm size is defined as total acres operated as opposed to the size of the individual operating unit within the watershed. The more inclusive definition is the appropriate one for our decision analysis.

based on actual distribution as opposed to what the farm operator perceives. It is our contention that the perceived risk is the driving force if risk does matter in the adoption decision. In this study, the Four Mile Creek operators were asked to rank eighteen tillage-rotation practice alternatives relative to their perceived riskiness. The farmers specified a number from one to eleven for each practice with one as the least risky and eleven as the most risky. These perceived risk ratings do allow comparisons of how risky one practice is perceived relative to another for any given farmer. The risk variable (RD) incorporates perceived risk into the adoption model and is measured as the difference in perceived riskiness between the conservation tillage practice being considered and the moldboard plow alternative. Hypothesizing that farmers perceive the moldboard plow tillage as less risky, then $\beta_7 < 0$ or as the perceived risk difference increases, the probability of adoption decreases.

Finally, yield differences (YCD) expected between conservation and moldboard plow tillage practices are important in determining relative profitability and in turn, adoption of conservation tillage. Farm operators reported expected yields for prospective primary tillage practices in the survey, and these responses were used to calculate the expected yield differences. Because the necessary data are not available, it is not possible to calculate the expected difference in net returns, which is the more appropriate decision criterion. For the study area, farmers generally expect higher yields from moldboard tillage relative to conservation tillage, thus it is hypothesized that $\beta_8 < 0$.

The linear probability model has a heteroscedastic error structure and under certain circumstances, improved prediction can be obtained by estimating this model using generalized or estimated-generalized least squares. However, the properties of these estimators need not be superior to those obtained by ordinary least squares, and given the nature of the data* as well as experimentation with other estimation techniques, we believe that the "OLS" technique is the appropriate alternative in this case. Further, there are alternative types of probability models, primarily the probit and logit models, which under specific circumstances can yield predictions with superior properties to those obtained utilizing the linear probability model. However, small sample size and other problems in the data render these probability models unsuitable for obtaining good predictors. Thus it is assumed in this investigation that the linear model offers a more appropriate vehicle for identifying variables of significance in explaining adoption. In estimating the model the observed values of $P_{ijh}$ take on the value one if the farmer chooses a tillage practice other than moldboard plowing and zero if the moldboard practice is selected. However, the probabilities must each be positive and sum to one. That is, where $P_{ijh}$ is the probability that reduced tillage will be chosen and $1-P_{ijh}$ is the probability that the moldboard option is chosen, then $P_{ijh} \geq 0$ and $1-P_{ijh} \geq 0$.

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*R.S. Pindyck and D.L. Rubinfeld. Econometric Models and Economic Forecasts. McGraw-Hill Book Co., 1976, pp. 238-254.

The empirical results from fitting the linear probability model are presented in Table 16. Although there are some problems with multicollinearity and a good deal of the variance in the model remains to be explained, the results are quite interesting. Generally, the signs of the estimated parameters are as hypothesized.

Table 16. Estimates of the conservation tillage adoption model for the Four Mile Creek Watershed

| Variable | Model<br>Coefficient | Std. error |
|---|---|---|
| Intercept | -.19 | -.33 |
| EXP | .0043 | 1.32 |
| ED | .079 | 1.65 |
| FS | -.00036 | -3.25 |
| TEN | .024 | .73 |
| DVJ | -.031 | -.59 |
| DVH | .19 | 3.56 |
| YCD | -.00057 | -.28 |
| RD | -.011 | -1.15 |
| $R^2$ | .11 | |
| F | 3.50 | |
| Obs. | 238 | |

These results do have several policy implications that deserve further exploration. Experience (EXP) of the farm operator has a positive impact on conservation tillage adoption, but the coefficient is significantly different from zero at only the 18 percent level. Operator's education (ED) has a positive and statistically significant (9% level) effect on the adoption of conservation tillage suggesting that the provision of educational programs may serve to enhance adoption of reduced tillage practices. Thus, human capital characteristics are important factors in the adoption decision and should be considered in formulating programs to promote conservation tillage practices.

The negative sign on the farm size (FS) and the statistically significant (1% level) effect imply that the larger the farm operation, the less likely reduced tillage practices will be adopted, other things equal. Thus, policies targeted to smaller operators will likely meet with better reception and increase reduced tillage adoption more readily than programs directed at all farm operators. This result is somewhat surprising since it is frequently argued that larger operators can spread the costs of improved information over more units, and thus have an incentive to acquire better information. If the practice is more profitable, these operators are more likely to be early adopters because they have more accurate expectations. Even though the tenure variable (TEN) is positive, it is not significantly different from zero. Theoretically, the outcome is not surprising if landowners recognize the value of soil productivity and the costs of erosion. Regardless of the landowners' level of direct participation in the operation of the farm, it is in the owner-operator's or owner-lessor's economic interests to ensure the utilization of practices that maximize the long run net return to the land investment.

The dummy coefficient for hilly land is positive and significant (1% level), indicating that adoption of conservation tillage is more probable on more erosive land. The willingness of farmers to adopt soil conserving practices is a function of the potential erosivity of the land, and in turn, the discounted future net benefits of such a choice. Related to the strong relationship between adoption and farmland topography is the fact that previous studies found a positive relationship between the degree of tenure and the utilization of soil erosion control practices, but none of these studies have held the erosion potential of the land constant. Thus the importance of tenure in these studies may be related to the topography of the farmland operated. The coefficient for the corn-soybean rotation dummy (DVJ) does not have the hypothesized sign but is not significantly different from zero. At least in the Four Mile Creek Watershed, no inducement for the adoption of conservation tillage results from the production of soybeans.

The expected yield difference (YCD) and the perceived risk difference (RD) coefficients both have the expected negative signs, but the risk parameter is significantly different from zero at only the 25 percent level and the yield difference estimate is not significant. These results do suggest that perceived risk difference between tillage practices may be an important factor in the adoption decision. With respect to policy formation, if farmer operators' perceptions of the risk differences relative to tillage practices are overstated, and there is some evidence that the differences in yield variability are insignificant,* then improved information (extension and education) programs may be able to alter these misperceptions and increase conservation tillage adoption with the associated benefits for soil loss control. Both the results of the Four Mile Creek survey and the study by Erbach, et al., indicate that expected and actual yield differences between tillage practices, with the exception of no-till, are not very significant and may explain why YCD was not significantly different from zero in the adoption model.

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*Erbach, D.C., W.G. Lovely, and G.E. Ayres. "Conservation and Conventional Systems for Continuous Corn." Misc. Bull. 14, Agriculture and Home Economics Experiment Station, Iowa State University, Ames, August 1980.

In summary, the results obtained from fitting the adoption model to the Four Mile Creek survey data are quite enlightening and useful in soil conservation policy formation. There has been much recent discussion and effort to target soil conservation programs to regions with serious soil loss problems. The results reported in this section suggest that targeting could conceivably be extended to the delivery of education and information programs to those farm operations more likely to participate.

The human capital and risk perception characteristics tend to have the anticipated impact on adoption. The farm structure variables generated some surprises. Farm size had a strong negative impact on adoption which was not anticipated and tenure did not have a significant impact. Finally, as might be hoped, potential erosivity served as a major inducement for conservation tillage adoption. Such findings should influence the direction of soil erosion control policy formation efforts that involve incentives for conservation tillage and related conservation practices.

# V. Effects of Rising Energy Prices on Nonpoint Source Pollution and Its Control*

## A. Introduction

Of concern to farmers, consumers, and policymakers alike is soil erosion and the concomitant problem of nonpoint source (NPS) pollution. The type of policy and the degree to which it should be applied are, however, hotly debated issues. Economists have been called upon to aid the decision-makers in developing NPS control policies that are optimal in terms of equity and efficiency considerations.

Most studies of the NPS pollution problem assume the existence of a set of farm inputs that are fixed in price, and then use programming techniques to estimate the costs of various pollution control options.** While useful as a first approximation, this approach ignores the need to coordinate public policy with shifting relative input costs.

One important input whose relative price is likely to change over the next ten to fifteen years is energy. An increasing world demand for energy, as well as OPEC pricing policies and political instability in the Persian Gulf, will combine to cause a relative increase in the price of energy. This increase will be manifested directly in higher fuel

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**A useful summary of such recent studies can be found in James S. Shortle, "Soil Depletion and Water Quality: A Case Study of Conjunctive Management of Natural Resources," (Ph.D. dissertation), Department of Economics, Iowa State University, Ames, 1981.

bills for farmers and indirectly in higher costs for farm inputs--fertilizers, herbicides, pesticides, and machinery.

Effective public policy, aimed at reducing NPS pollution, must recognize the increasing relative cost of farm fuel and energy-related inputs. The purpose of this section is to assess the impacts of rising energy prices on soil erosion and on the effectiveness of NPS pollution control policies. This is accomplished by evaluating the impact of rising energy prices on soil erosion in the absence of NPS pollution control policies and in the presence of different NPS control policies. It is hypothesized that rising relative energy prices will cause a reduction in soil loss, but the magnitude is uncertain. Additionally, it is hypothesized that rising relative energy prices combined with soil conservation policies will have a more profound impact in reducing soil loss but little is known about the interaction between these factors. Rising energy prices may reduce or enhance the effectiveness of erosion control policies. Understanding of the interaction between market forces and government intervention is information crucial to policy decisionmaking.

It is important to note that this section is based upon a programming model of agricultural production in the Iowa River Basin. Although the Four Mile Creek Watershed, which is the focus of this EPA study, is not part of the Iowa River Basin, use of this programming model and region is justified by four factors.

First, the available resources and time were inadequate to develop an original model for the Four Mile Creek Watershed, but an excellent model, requiring some modification, was available for the Iowa River Basin. Second, the Iowa River Basin model includes a larger area with a more varied production environment, thus affording a more representative response to rising relative energy prices. Third, one of the specific soil aggregates in the Iowa River Basin is almost identical to the Four Mile Creek area and should adequately reflect farmer response in this area. Finally, data from the Four Mile Creek survey were used to modify the coefficients of the Iowa River Basin model. Thus, this analysis should adequately reflect farmer response to rising relative prices for energy in the Four Mile Creek watershed, and in addition provide more general information about farmers' responses to rising energy prices when NPS policy is in effect.

## B. Programming Model

To examine how NPS pollution control policy is affected by prevailing energy prices, a programming model of farm production was developed for that part of the Iowa River Basin that lies above the Coralville Reservoir. This twenty-one county area consists of 1,899,600 acres of cropland and 61,400 acres of permanent pasture. The study area encompasses farmland that ranges from gently sloping prairie in North Central Iowa to steeply sloped hills in Eastern Iowa.

For purposes of this study the farmland is aggregated into nine basic soil areas according to agronomic and physical characteristics of the soils. Table 17 shows the relationship between the soil aggregates used in this analysis and the Soil Association Area designations made by the Soil Conservation Service. Table 17 also lists the predominate soil types occurring in the study aggregates and their normalized percentages.

Each of the nine soil aggregates was assumed to consist of similar

Table 17. Soil Type Composition of Study Aggregates

| Study aggregate | Soil association area | Soil type and slope | | Normalized percent |
|---|---|---|---|---|
| 1 | 11 | 108A | Wadena L | (14) |
| | | 559A | Talcot CL | (26) |
| | | 138B1 | Clarion L | (30) |
| | | 87A | Colo-Zook CP | (30) |
| 2 | 12,14,17,18 | 507A | Canisteo SICL | (22) |
| | | 55A | Nicollet L | (22) |
| | | 107A | Webster SICL | (19) |
| | | 138B1 | Clarion L | (22) |
| | | 138C2 | Clarion L | (12) |
| 3 | 13,117 | 107A | Webster SICL | (46) |
| | | 138B1 | Clarion L | (27) |
| | | 138C2 | Clarion L | (14) |
| | | 138D2 | Clarion L | (6) |
| | | 62E2 | Sturden L | (7) |
| 4 | 15 | 107A | Webster SICL | (29) |
| | | 55A | Nicollet L | (32) |
| | | 138B1 | Clarion L | (29) |
| | | 138C2 | Clarion L | (10) |
| 5 | 7 | 87A | Colo-Zook CP | (38) |
| | | 178A | Waukee L | (17) |
| | | 220A | Nodaway SIL | (10) |
| | | 315A | Alluvial Land | (10) |
| | | 177B1 | Saude L | (25) |
| 6 | 57 | 129A | Chaseburg SICL | (17) |
| | | 163B | Fayette SICL | (26) |
| | | 163C2 | Fayette SICL | (22) |
| | | 163D2 | Fayette SICL | (21) |
| | | 163E2 | Fayette SICL | (14) |
| 7 | 46 | 280A | Mahaska SICL | (12) |
| | | 281B1 | Otley SICL | (35) |
| | | 281C2 | Otley SICL | (21) |
| | | 281D2 | Otley SICL | (32) |
| 8 | 56,77 | 119A | Muscatine SICL | (16) |
| | | 120B1 | Tama SICL | (26) |
| | | 120C2 | Tama SICL | (32) |
| | | 120D2 | Tama SICL | (17) |
| | | 162E2 | Downs SIL | (9) |
| 9 | 55,59,65,78 | 119A | Muscatine SICL | (24) |
| | | 120B1 | Tama SICL | (41) |
| | | 120C2 | Tama SICL | (35) |

Derived from Soil Conservation Service Soil Survey Maps.

farms of 300 acres each, and a "typical" or "representative" farm was constructed for each soil aggregate. Consistent with the cropping practices in the study area, each representative farm was given the option of growing continuous corn, corn-beans, or corn-corn-oats-meadow-meadow rotations.* The representative farms could choose from a list of tillage systems that included: fall moldboard plowing, fall chisel plowing, spring chisel plowing, spring disking, and no-till planting. For any tillage system the representative farmer could use straight row or contour cultivation and could terrace the cropland.

The livestock activities assumed available to each representative farm included farrow-to-finish swine operations, beef cow-calf herds, feeder steer finishing, and dairy enterprises.** While livestock production activities have little direct effect on soil loss, the forage crop requirements of livestock will reduce the number of acres available for row crops and will absorb some increases in forage production.

To determine a baseline solution for crop and livestock production in the study area, a linear programming model was developed which maximized total net farm income. The objective function of the model was

$$Z = \sum_{i=1}^{9} R_i$$

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*The following crop price assumptions were used: Corn - $2.50/bu; Soybeans - $6.50/bu; Oats - $1.40/bu; and Hay - $65/ton.

**The following livestock price assumptions were used: Steers - $62/hwt; Calves - $70/hwt; Hogs - $40/hwt; and Milk - $10.50/hwt.

where Z is the net total farm income for the basin and $R_i$ is the total net farm income in the i-th soil aggregate. As the model is constructed, each soil aggregate is independent of the others and the baseline solution is the sum of the solutions obtained from the nine models, one for each farm. (A more detailed description of the model can be found in the Appendix.) Net farm income for each soil aggregate equals the total net income of the farms in that aggregate. To obtain an estimate of net income for each representative farm in soil aggregate i, $R_i$ is divided by the actual number of farms in the i-th soil aggregate.

Net income is equal to the total receipts from crop and livestock sales less all costs except those constituting returns to farmland and management.* All labor inputs are assumed to be purchased so that net income is exclusive of the returns to labor provided by the farm operator. The net income estimates are for a representative crop year under current technological conditions, given expected crop and livestock prices and input costs.

Crop yield estimates used for each study aggregate were the weighted average of the crop yield estimates of each soil type appearing in the soil aggregate. Specific crop yield estimates for each soil type were from estimates published by Iowa State University.**

The basic recommended fertilizer levels for each study aggregate were constructed by first finding the recommended fertilizer levels for each soil type within a particular study aggregate, and then taking the weighted average of the fertilizer levels for the soil types. Fertilizer recommendations for the soil types were derived from two extension publications.*

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*It is assumed that farmers do not hold inventories of inputs or outputs from one production year to the next.

**Iowa State University, "Special Report No. 66," Agriculture and Home Economics Experiment Station and Cooperative Extension Service, Ames.

To determine the cost of operating and maintaining a particular machinery complement, an enterprise budget generator from the Cooperative Extension Service (ISU) was used. This computer routine provides a means of delineating machinery complements data, performing the needed computations, and producing the fixed and variable costs associated with the machinery complements. To allow for a more direct analysis of fuel use, the fuel use component was separated from the other costs of the machinery complement.

Farms in the model purchase diesel fuel to perform field operations and purchase propane gas to dry corn. The diesel fuel requirements were developed from data prepared by the Cooperative Extension Service (ISU), which give the gallons per acre of diesel fuel required to perform various field operations on a Central Iowa loam soil (see Table 18). A coefficient for each crop production activity in the model was constructed by summing the requirements for each field operation encomposing that activity. The coefficients are inflated by five percent for crop production activities involving contour tillage.

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*Iowa State University, "Summary of Soil Test Results," Number AG-G5, Cooperative Extension Service, Ames; and Iowa State University, "Selected Information for Iowa Soil Types," Number AG-G6, Cooperative Extension Service, Ames.

Table 18. Fuel Requirements for Various Rotations and Tillage Systems

| Rotation | Gallons per acre<br>Light | Medium* | Heavy |
|---|---|---|---|
| Continuous corn, moldboard, fall | 6.28 | 7.15 | 8.40 |
| Corn-beans, moldboard, fall | 4.57 | 5.54 | 5.95 |
| Continuous corn, chisel, fall | 5.96 | 6.95 | 7.10 |
| Corn-beans, chisel, fall | 5.89 | 5.69 | 5.98 |
| Continuous corn, chisel, spring | 5.96 | 6.95 | 7.10 |
| Corn-beans, disk, spring | 4.46 | 5.04 | 4.88 |
| Corn-beans, double chisel, fall | 4.61 | 5.44 | 6.06 |
| Corn-meadow, moldboard, fall | 2.70 | 3.11 | 3.65 |
| Corn-meadow, chisel, fall | 2.99 | 3.38 | 3.79 |
| Corn-meadow, chisel, spring | 2.99 | 3.38 | 3.79 |
| Continuous corn, no-till | 3.00 | 3.35 | 3.61 |
| Corn-beans, no-till | 2.44 | 2.79 | 3.05 |

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*These figures are for a Central Iowa loam soil. The "light" and "heavy" column entries represent adjustments to these basic figures to reflect changes in fuel consumption. For contour tillage, these figures are inflated by five percent.

U.S. Dept. of Agriculture, Cooperative Extension Service, Iowa State University, "Fuel Requirements for Field Operations," prepared by George E. Ayres, November, 1976.

The propane gas requirements for corn drying were assumed to be 0.1856 gallons per bushel. This figure was derived from information contained in the output of the Budget Generator. The fuel requirements for livestock operations were taken from Extension Service worksheets.

The aggregate level of net farm income for the study basin will be associated with a level of gross soil erosion of

$$E = \sum_{i}\sum_{r}\sum_{j}\sum_{t} SE_{rijt} \times A_{rijt}$$

where $SE_{rijt}$ is the gross soil loss per acre of the r-th rotation in the i-th study aggregate utilizing the j-th tillage system and t-th practice, and $A_{rijt}$ is the number of acres employing the r-th rotation in the i-th aggregate with the j-th tillage system and the t-th practice.

Predictions of soil losses in the model are made by application of the Universal Soil Loss Equation. This equation is an erosion model developed to predict long-run average annual erosion, and is normally stated as

$$SE = RKLSCP$$

where:

SE is the soil loss in tons per acre per year;

R is the rainfall or runoff factor;

K is the soil erodibility factor;

L is the slope-length factor;

S is the slope-steepness factor;

C is the cover and management factor;

P is the support practice factor.

A detailed discussion of the model and of the various parameters and their determination can be found in the USDA publication Predicting Rainfall Erosion Losses - A Guide To Conservation Planning.*

The parameter "R" is a measure of the frequency and erosivity of rainfall in a given location. "K" is a measure of how readily a soil erodes and is dependent upon physical properties of soils. The product of the parameters "L" and "S" is known as the topographic factor. The product RKLS is the amount of soil loss that would result if a particular field were continuously fallow. The cover and management factor "C" gives the ratio of soil loss from land cropped under given conditions to the corresponding loss from clean-tilled, continuously fallow. The value of "C" is dependent upon crop sequence, residue and management practices, and upon the stage of development of vegetative cover at which rainfall occurs. The support practice factor "P" is the ratio of soil loss with a specific support practice to the corresponding loss with up and down slope tillage. Support practices are activities which slow runoff--the most important of which is contour tillage.

The values of RKLS for terraced and for unterraced soil types, and the value of P for contouring were obtained for all soil types in the study area from data developed by Harmon, Knutson, and Rosenberry.[*]

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*U.S. Dept. of Agriculture. Predicting Rainfall Erosion Losses - A Guide to Conservation Planning, December, 1978.

The cover and management factors for the alternative crop production activities on each soil type were also obtained from data specific to Iowa.[**] On the basis of these data the gross erosion on each soil type for any given crop production activity was computed.

## C. Baseline Solution

To determine a baseline solution for the programming model, net farm income was maximized for each of the soil aggregates (and thus for each representative farm in the study aggregates) using 1978 prices for inputs and outputs. Total net farm income for the river basin was $324,853,007. Associated with the baseline production solution was gross erosion in the river basin of 16,968,093 tons or 8.7 tons/acre.

## D. No Restrictions Solutions

In order to analyze the effects of higher relative energy prices, the costs of machinery, nitrogen, phosphorus, potassium, corn herbicide, bean herbicide, and insecticide were adjusted in accord with 1985 and 1990 price projections. Price projections for energy inputs were obtained from the U.S. Department of Energy.[***] Energy input quantities used in the production of agricultural inputs were taken from data compiled by Pigeon.*

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[*] U.S. Dept. of Agriculture, Soil Depletion Reference. Report on Southern Iowa River Basins, by L. Harmon, Russell Knutson, and Paul Rosenberry. March 1979.

[**] U.S. Dept. of Agriculture, Soil Conservation Service, Work Unit Technical Guide, Section III-B, April 1964.

[***] U.S. Dept. of Energy, "Midterm Energy Projections for the U.S.," Energy Information Administration Annual Report to Congress - 1978, Vol. 3, Supplement 1, Government Printing Office, July 1979.

The coal, natural gas, oil, and electricity requirements for the manufacture of the fertilizers, herbicides, insecticides, and machinery were entered in the model, and the costs of the farm inputs were increased as projected energy prices increased. Diesel fuel and natural gas costs were entered directly for each time period.

The overall results obtained by solving the programming model for projected 1985 and 1990 energy prices are that higher relative prices for energy inputs tend to decrease both soil erosion and the amount of fertilizer used by farmers. This reduction occurs because conservation tillage practices are less energy intensive, and because continuous corn production is both more energy-intensive and more fertilizer-intensive. Table 19 indicates a switching away from continuous corn to corn-bean rotations and a partial switching from fall chiseling to no-till planting as energy prices rise.

The effect of energy price-induced alterations in rotations and tillage practices is shown in more detail in Table 20. By 1990, gross erosion for the river basin falls by 3.7 million tons (a 22% decrease) with no soil loss restrictions, and annual per acre erosion falls from 8.65 to 6.79 tons. Also by 1990, nitrogen use decreases by over 56 million pounds for the river basin as a whole (a 35% drop), with decreases in potassium and phosphorus also occurring.

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*Edward R. Pigeon, "Energy Conservation Possibilities in Corn Production on a Central Iowa Farm," Masters Thesis, Department of Economics, Iowa State University, Ames, 1977.

Table 19. Acreage in Various Rotations and Tillage Systems With Increasing Energy Prices (No Soil Loss Policy).

| Cropping Practice | 1978 | 1985 | 1990 |
|---|---|---|---|
| Continuous corn | | | |
| Fall chisel | 519,797 | 24,057 | -0- |
| Corn-beans | | | |
| Fall chisel | 1,039,595 | 1,375,313 | 1,399,368 |
| No-till | -0- | 147,794 | 147,794 |
| Total | 1,039,595 | 1,523,107 | 1,547,162 |
| CCOMM | | | |
| Fall moldboard | 35,779 | 58,015 | 58,015 |
| Fall chisel | 304,471 | 304,471 | 304,471 |
| Total | 304,250 | 361,486 | 362,486 |
| Permanent pasture | 61,435 | 51,429 | 51,429 |

Table 20. River Basin Results With and Without Soil Loss Restrictions and Rising Energy Prices

| | No restrictions | | | 10T restrictions | | | 5T restrictions | | | 3T restrictions | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 |
| Total net farm income ($ millions) | 325 | 287 | 262 | 324 | 286 | 261 | 307 | 271 | 247 | 281 | 246 | 224 |
| Decrease from baseline level ($ millions) | - | 38 | 63 | 0.6 | 39 | 64 | 18 | 54 | 78 | 44 | 79 | 101 |
| Total erosion (million/tons) | 17.0 | 13.4 | 13.3 | 13.1 | 12.7 | 12.6 | 7.8 | 7.7 | 7.6 | 5.44 | 5.43 | 5.39 |
| Avg. erosion (tons/A) | 8.65 | 6.83 | 6.79 | 6.70 | 6.47 | 6.40 | 3.95 | 3.94 | 3.91 | 2.77 | 2.77 | 2.75 |
| Corn (millions bushels) | 132 | 92 | 89 | 131 | 92 | 89 | 119 | 92 | 82 | 110 | 79 | 74 |
| Soybeans (millions bushels) | 22.2 | 32.1 | 32.4 | 21.7 | 31.4 | 31.8 | 21.2 | 27.5 | 29.5 | 19.8 | 26.6 | 27.5 |
| Cows (1000 hd) | 122 | 122 | 122 | 122 | 122 | 122 | 154 | 155 | 154 | 157 | 157 | 157 |
| Steers (1000 hd) | 88 | 61 | 61 | 88 | 61 | 61 | 88 | 61 | 61 | 88 | 61 | 61 |
| Nitrogen (millions lbs) | 160 | 106 | 104 | 157 | 105 | 102 | 149 | 106 | 94 | 143 | 95 | 89 |
| Phosphorus (millions lbs) | 106.7 | 104.6 | 104.5 | 106.5 | 104.4 | 104.3 | 105.3 | 103.1 | 103.0 | 103.9 | 101.6 | 101.5 |
| Potassium (millions lbs) | 60.8 | 56.5 | 56.4 | 60.7 | 56.4 | 56.3 | 58.9 | 56.2 | 55.4 | 57.9 | 54.5 | 54.1 |
| Diesel (millions gal) | 12.8 | 11.0 | 10.6 | 12.6 | 11.1 | 10.7 | 11.7 | 10.8 | 9.9 | 11.2 | 10.5 | 8.9 |
| Propane (millions gal) | 24.1 | 12.0 | 11.9 | 24.0 | 12.0 | 11.9 | 22.6 | 11.7 | 11.1 | 20.7 | 10.5 | 10.2 |
| Contour (1000 A) | 0 | 0 | 0 | 322 | 104 | 105 | 396 | 431 | 433 | 177 | 259 | 270 |
| No-till (1000 A) | 0 | 148 | 148 | 21 | 112 | 111 | 208 | 234 | 327 | 461 | 466 | 540 |
| Terraced (1000 A) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 102 | 32 | 20 |

"X" T Indicates that the policy option considered restricted soil loss to an average of X tons per acre per farm.

The production of soybeans increases, and the production of corn decreases when energy prices rise. The decrease in corn production results in a decrease in steer finishing operations. As expected, higher relative energy prices mean lower net income and a decrease in the amount of fuels used.

The sensitivity of the parameters of the model was tested by running programming solutions for "low" 1985 energy price projections and for 1995 projections. The results of sensitivity tests were as expected. The farm-level adjustments for the "low" 1985 projections were intermediate of the results for the 1978 energy prices and the regular 1985 projections.

The solution values for the 1995 price levels were very similar to those obtained under 1990 price levels. Since technology is fixed in the model, there are limited possibilities for energy-saving substitutions in farm production activities. As relative prices for energy rise, energy-saving substitutions are quickly exhausted. The sensitivity test shows that total erosion for the river basin falls less than one percent when 1995 prices replace 1990 prices, and total corn production also decreases less than one percent.[*]

## E. Erosion Control Solutions

In solutions where alternative control strategies are implemented, the model is modified by imposing additional restrictions on the selection of activities. Two alternative control strategies were considered--soil loss restrictions and soil loss reduction subsidies.

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[*] Erosion decreased by approximately 5000 tons and corn production by 28,000 bushels.

The soil loss restriction strategy imposed ten, five, and three-ton restrictions on the average per acre erosion on each farm. That is, each farm is allowed only those activities that result in an average per acre soil loss that is less than or equal to a specified level. After imposing each soil loss restriction, energy prices were increased to show how a particular control level interacted with rising energy prices.

The erosion-reduction subsidy strategy allows in turn for payments to farms of $1, $6, $10, $14 for each ton of soil abated from the baseline level. Each farm is allowed to alter rotations, tillage systems, cropping practices, and livestock activities in a manner that maximizes net farm income--given that the farm will receive $X/ton for a reduction in soil erosion from the baseline level. After generating each subsidy level, energy prices were increased to show how a particular subsidy level interacted with rising energy prices.

The programming results for the soil loss restriction policy are presented in Table 20. The results clearly indicate that rising energy prices make the soil loss restriction strategy more restrictive relative to soil erosion and fertilizer use. Table 20 shows that for a given level of control, higher energy prices cause a reduction in soil erosion beyond that level which is obtained when energy prices are constant. For instance, with 1978 prices at the ten-ton level of restriction erosion for the river basin is 6.7 tons/acre. As prices rise to 1985 and 1990 levels, erosion falls to 6.47 tons/acre and 6.40 tons/acre, respectively.

The imposition of soil loss restrictions, which forces cropping rotations to less fertilizer intensive crops, causes a decrease in fertilizer levels. At 1978 energy prices, a three-ton per acre average soil loss restriction for each farm will cause a decrease from the baseline level of 17 million pounds of nitrogen used in the river basin. Rising energy prices combined with soil loss restrictions will result in a greater decrease in fertilizer use than would occur in the presence of soil loss restrictions alone.

Rising energy prices and soil loss restrictions have a synergistic effect on fuel use when the control strategies involve five or three-ton restrictions. Restrictions on soil loss work to diminish the amount of beans grown, but since bean production is less energy intensive than corn production, higher energy prices cause more beans to be grown. A three-ton restriction combined with 1990 projected energy prices results in more soybeans produced than in the baseline solution, but less soybeans than in the absence of soil loss restrictions.

More restrictive limits on soil erosion work to increase the size of the cow-calf operations. The impact of higher energy prices on corn production works to decrease the size of the steer finishing operations in all cases.

A ten-ton per acre soil loss limit would be met primarily by contouring. Rising energy prices would cut this amount of cropland contoured by two-thirds, and cause a very large increase in energy-efficient no-till planting. At more restrictive soil loss limits, rising energy prices increase both the amount of land contoured and the amount of no-till planting. However, the relatively energy-intensive terracing that occurs at the three-ton limit is diminished dramatically by higher energy prices.

The programming results for the soil loss reduction subsidy policy are shown in Table 21. In some respects, the results of the subsidy policy are qualitatively similar to the results of the erosion restriction policy. For instance, under either policy higher energy prices tend to reduce fertilizer and fuel use, decrease corn and steer production, and increase soybean production.

With a particular level of restriction imposed, higher energy prices unambiguously reduce the level of erosion (with the exception of 1978 3T and 1985 3T in which case the level of erosion is constant). The impact of higher energy prices on erosion with the subsidy program in effect depends on the subsidy level offered. In general, the lower the subsidy level offered, the more likely that higher energy prices will bring about a decrease in erosion. If the subsidy offered for abatement is $6/ton, then as energy prices rise to the 1990 projected level, erosion for the river basin will fall from 4.67 tons/acre to 4.22 tons/acre. With a $14/ton abatement subsidy offered, as energy prices rise to the 1990 projected level, erosion will increase from 1.65 tons/acre to 1.72 tons/acre. Concomitantly, at the $6/ton level the cost of the abatement subsidies for the river basin as a whole will rise from $46.8 million to $52.1 million as energy prices rise from their 1978 level to the 1990 projected level. If an erosion abatement subsidy of $14/ton is offered, the cost of the subsidies will decrease from $192.1 million to $190.5

Table 21. River Basin Results Under Abatement Subsidy Programs and Rising Energy Prices

| | $1/ton | | | $6/ton | | | $10/ton | | | $14/ton | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 |
| Net farm income w/subsidy ($ millions) | 330.5 | 292.5 | 281.8 | 366.1 | 329.4 | 319.5 | 404.0 | 372.0 | 362.7 | 451.8 | 420.4 | 411.1 |
| Net farm income less subsidy | 324.4 | 286.4 | 275.7 | 319.3 | 277.4 | 267.4 | 293.0 | 254.7 | 245.9 | 259.7 | 229.5 | 220.6 |
| Cost of subsidy ($ millions) | 6.1 | 6.1 | 6.1 | 46.8 | 52.0 | 52.1 | 111 | 117.3 | 116.8 | 192.1 | 190.9 | 190.5 |
| Total erosion (millions tons) | 10.9 | 10.8 | 10.8 | 9.2 | 8.3 | 8.2 | 5.9 | 5.2 | 5.3 | 3.2 | 3.3 | 3.4 |
| Ave. erosion (tons/A) | 5.56 | 5.55 | 5.55 | 4.67 | 4.24 | 4.22 | 2.99 | 2.67 | 2.69 | 1.65 | 1.70 | 1.72 |
| Corn (millions bushels) | 131 | 92 | 90 | 125 | 92 | 84 | 111 | 83 | 76 | 98 | 75 | 69 |
| Soybeans (millions bushels) | 21.9 | 31.4 | 31.9 | 22.2 | 27.2 | 29.1 | 20.2 | 25.2 | 27.1 | 18.5 | 25.0 | 26.5 |
| Cows (1000 head) | 122 | 122 | 122 | 129 | 138 | 138 | 158 | 158 | 158 | 158 | 158 | 158 |
| Steers (1000 head) | 88 | 61 | 61 | 88 | 61 | 61 | 88 | 61 | 61 | 88 | 61 | 61 |
| Nitrogen (millions lbs) | 159 | 105 | 102 | 154 | 102 | 93 | 141 | 100 | 89 | 134 | 100 | 92 |
| Phosphorus (millions lbs) | 106.7 | 104.5 | 104.4 | 106.3 | 103.9 | 103.9 | 104.3 | 102.6 | 102.1 | 103.4 | 101.7 | 101.2 |
| Potassium (millions lbs) | 60.9 | 56.5 | 56.4 | 59.8 | 57.1 | 56.3 | 58.0 | 54.9 | 54.5 | 56.6 | 53.2 | 53.0 |
| Diesel (millions gal) | 12.3 | 10.8 | 10.7 | 12.0 | 9.2 | 9.0 | 10.1 | 8.1 | 8.0 | 9.1 | 8.8 | 8.7 |
| Propane (millions gal) | 24.1 | 12.1 | 12.0 | 24.1 | 11.9 | 11.4 | 21.4 | 10.8 | 10.4 | 18.7 | 9.8 | 9.5 |
| Contour (1000 A) | 398 | 400 | 400 | 449 | 503 | 503 | 288 | 327 | 327 | 100 | 100 | 100 |
| No-till (1000 A) | 100 | 118 | 118 | 0 | 638 | 638 | 603 | 1105 | 1105 | 1071 | 1105 | 1105 |
| Terraced (1000 A) | 0 | 0 | 0 | 0 | 0 | 0 | 32 | 32 | 32 | 32 | 32 | 32 |

$X/ton indicates that a subsidy of $X is paid for each ton of erosion abated from the base[illegible]evel.

as energy prices change from 1978 to 1990 projected levels.

Why higher energy prices reinforce the impact of soil loss restriction policy but may not reinforce the impact of soil erosion abatement subsidy policy can be seen by examining soil loss in each study aggregate. Table 22 shows that in the absence of soil loss restrictions, rising energy prices bring about the greatest decreases in soil erosion in those study aggregates that have the most erosive soil. For instance, the amount of erosion in study aggregate 6 is cut by almost 40 percent when energy prices increase from 1978 levels to projected 1985 levels.

With soil loss restrictions imposed, higher energy prices bring about a reduction in soil erosion primarily on the less erosive study aggregates. This can be seen by examining the 5 tons/acre farm average restriction for 1978 energy prices and 1985 projected energy prices. Study aggregates 6, 7, 8, and 9 are constrained at the five-ton level and their erosion remains at that level when energy prices rise. Study aggregates 1, 2, and 4 are unaffected when energy prices rise to the 1985 projected levels. Erosion in study aggregate 3 falls from 4.1 tons/acre to 3.7 tons/acre and erosion decreases in study aggregate 5 from 1.3 tons/acre to 1.2 tons/acre when energy prices rise from 1978 to 1985 projected levels.

When the soil loss restrictions policy is replaced by a subsidy policy, the impact of higher energy prices becomes dependent on the level of subsidy offered. For the river basin as a whole, the lower the level of subsidy, the more likely that rising energy prices will

Table 22. Study Aggregate Erosion (in 1000s of Tons and Tons/Acre) With and Without Soil Loss Restrictions

| Study | No restrictions | | | 10 tons/farm ave. | | | 5 tons/farm ave. | | | 3 tons/farm ave. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| aggregate | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 |
| 1 | 90<br>(1.4) | 87<br>(1.4) | 87<br>(1.4) | * | * | * | * | * | * | * | * | * |
| 2 | 1458<br>(2.9) | 1458<br>(2.9) | 1424<br>(2.8) | * | * | * | * | * | * | * | * | * |
| 3 | 195<br>(4.1) | 176<br>(3.7) | 161<br>(3.4) | * | * | * | * | * | * | 142<br>(3.0) | R | R |
| 4 | 230<br>(2.9) | 230<br>(2.9) | 224<br>(2.8) | * | * | * | * | * | * | * | * | * |
| 5 | 208<br>(1.3) | 204<br>(1.2) | 204<br>(1.2) | * | * | * | * | * | * | * | * | * |
| 6 | 3723<br>(21.7) | 2355<br>(13.7) | 2355<br>(13.7) | 1716<br>(10.0) | R | R | 858<br>(5.0) | R | R | 515<br>(3.0) | R | R |
| 7 | 2296<br>(11.6) | 1681<br>(8.5) | 1681<br>(8.5) | 1977<br>(10.0) | * | * | 988<br>(5.0) | R | R | 593<br>(3.0) | R | R |
| 8 | 5989<br>(13.3) | 4557<br>(10.1) | 4557<br>(10.1) | 4491<br>(10.0) | R | R | 2296<br>(5.0) | R | R | 1347<br>(3.0) | R | R |
| 9 | 2780<br>(9.7) | 2650<br>(9.3) | 2626<br>(9.2) | * | * | * | 1429<br>(5.0) | R | R | 857<br>(3.0) | R | R |

* Indicates that study aggregate erosion equals the "no restrictions" value.

R Indicates that study aggregate erosion equals the given restricted value.

(Terms in parentheses are tons/acre.)

cause a decrease in erosion. At low subsidy levels (say $1/ton or $6/ton) an increase in energy prices induces a switch in both continuous corn and corn-beans rotations from conventional tillage methods to no-till planting--thus affording a decrease in erosion. When subsidy levels are high (say $10/ton or $14/ton) a large amount of no-till planting occurs at the 1978 price solution and the main impact of higher energy prices is to induce a switch from no-till continuous corn to the more erosive no-till corn-beans rotations. Unlike the soil loss restriction policy, farmers are not constrained by the subsidy policy to keep erosion below a particular value. In order to maximize net income, farmers are willing at high subsidy levels to accept a lower subsidy in order to maximize net returns albeit in a more erosive manner.

It is clear that for the river basin as a whole, the higher the subsidy level, the more likely it is that higher energy prices may increase the level of erosion. When individual study aggregates are examined, a number of exceptions to the rule become evident.

Table23 shows that for study aggregate 7 the level of erosion increases when prices rise from 1978 to projected 1985 levels when subsidies of $1/ton or $6/ton are offered. Study aggregate 3, however, experiences a decrease in erosion when prices increase to projected 1985 levels even with a $14/ton subsidy available.

## F. Sub-Area Impacts

A better understanding of the adjustments in farm operations that occur when energy prices rise and soil loss is restricted is gained by examining adjustment within a specific study aggregate. Table24 shows

Table 23. Study Aggregate Erosion (in 1000s of Tons and Tons/Acre) With and Without Subsidies

| Study aggregate | No restrictions | | | $1/T subsidy | | | $6/T subsidy | | | $10/T subsidy | | | $14/T subsidy | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 |
| 1 | 90<br>(1.4) | 87<br>(1.4) | 87<br>(1.4) | 90<br>(1.4) | 87<br>(1.4) | 87<br>(1.4) | 81<br>(1.3) | 87<br>(1.4) | 87<br>(1.4) | 81<br>(1.3) | 87<br>(1.4) | 87<br>(1.4) | 81<br>(1.3) | 87<br>(1.4) | 87<br>(1.4) |
| 2 | 1458<br>(2.9) | 1458<br>(2.9) | 1424<br>(2.8) | 1445<br>(2.9) | 1424<br>(2.8) | 1419<br>(2.8) | 1312<br>(2.6) | 776<br>(1.6) | 776<br>(1.6) | 715<br>(1.4) | 776<br>(1.6) | 776<br>(1.6) | 715<br>(1.4) | 776<br>(1.6) | 776<br>(1.6) |
| 3 | 195<br>(4.1) | 176<br>(3.7) | 161<br>(3.4) | 139<br>(2.9) | 145<br>(3.1) | 139<br>(2.9) | 120<br>(2.5) | 89<br>(1.9) | 83<br>(1.8) | 65<br>(1.4) | 38<br>(0.8) | 38<br>(0.8) | 58<br>(1.2) | 31<br>(0.7) | 31<br>(0.7) |
| 4 | 230<br>(2.9) | 230<br>(2.9) | 224<br>(2.8) | 230<br>(2.9) | 216<br>(2.7) | 224<br>(2.8) | 209<br>(2.6) | 122<br>(1.5) | 122<br>(1.5) | 112<br>(1.4) | 112<br>(1.4) | 122<br>(1.5) | 112<br>(1.4) | 112<br>(1.4) | 122<br>(1.5) |
| 5 | 208<br>(1.3) | 204<br>(1.2) | 204<br>(1.2) | 208<br>(1.3) | 204<br>(1.2) | 204<br>(1.2) | 195<br>(1.2) | 203<br>(1.2) | 203<br>(1.2) | 189<br>(1.1) | 189<br>(1.1) | 203<br>(1.2) | 189<br>(1.1) | 189<br>(1.1) | 203<br>(1.2) |
| 6 | 3723<br>(21.7) | 2355<br>(13.7) | 2355<br>(13.7) | 2026<br>(11.8) | 1841<br>(10.7) | 1841<br>(10.7) | 1266<br>(7.4) | 1144<br>(6.7) | 1144<br>(6.7) | 147<br>(0.8) | 159<br>(0.9) | 159<br>(0.9) | 147<br>(0.8) | 159<br>(0.9) | 159<br>(0.9) |
| 7 | 2296<br>(11.6) | 1681<br>(8.5) | 1681<br>(8.5) | 1538<br>(7.8) | 1681<br>(8.5) | 1681<br>(8.5) | 1404<br>(7.1) | 1441<br>(7.3) | 1441<br>(7.3) | 609<br>(3.1) | 509<br>(2.6) | 527<br>(2.7) | 503<br>(2.5) | 503<br>(2.5) | 509<br>(2.6) |
| 8 | 5989<br>(13.3) | 4557<br>(10.1) | 4557<br>(10.1) | 3516<br>(7.8) | 3526<br>(7.9) | 3526<br>(7.9) | 2965<br>(6.6) | 2867<br>(6.3) | 2867<br>(6.3) | 2513<br>(5.6) | 2235<br>(5.0) | 2235<br>(5.0) | 323<br>(0.7) | 341<br>(0.8) | 341<br>(0.8) |
| 9 | 2780<br>(9.7) | 2650<br>(9.3) | 2626<br>(9.2) | 1722<br>(6.0) | 1754<br>(6.1) | 1754<br>(6.1) | 1616<br>(5.7) | 1582<br>(5.5) | 1553<br>(5.4) | 1440<br>(5.0) | 1136<br>(4.0) | 1136<br>(4.0) | 1118<br>(3.9) | 1136<br>(4.0) | 1136<br>(4.0) |
| Total | 17.0<br>(8.65) | 13.4<br>(6.83) | 13.3<br>(6.79) | 10.9<br>(5.56) | 10.8<br>(5.55) | 10.8<br>(5.55) | 9.2<br>(4.67) | 8.3<br>(4.24) | 8.2<br>(4.22) | 5.9<br>(2.99) | 5.2<br>(2.67) | 5.3<br>(2.69) | 3.2<br>(1.65) | 3.3<br>(1.70) | 3.4<br>(1.72) |

*Numbers in parentheses are average ton of soil loss per acre for the respective soil aggregate, year, and policy option.

Table 24. Total Area in Various Rotations and Tillage Systems (in 1000s of Acres) for Soil Aggregate 8 With and Without Restrictions

| | No restrictions | | | 10 tons/farm ave. | | | 5 tons/farm ave. | | | 3 tons/farm ave. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 |
| Continuous corn | | | | | | | | | | | | |
| Fall chisel | 81 | 0 | * | 77 | 0 | * | 19 | 0 | 0 | 0 | 0 | 0 |
| No-till | 0 | 0 | * | 4 | 0 | * | 43 | 0 | 0 | 63 | 0 | * |
| Spring chisel (T) | 0 | 0 | * | 0 | 0 | * | 0 | 0 | 0 | 23 | 0 | * |
| Corn-beans | | | | | | | | | | | | |
| Fall chisel | 162 | 189 | * | 155 | 189 | * | 39 | 34 | 0 | 0 | 0 | * |
| No-till | 0 | 54 | * | 7 | 54 | * | 87 | 155 | 189 | 126 | 189 | * |
| Fall chisel (C) | 0 | 0 | * | 0 | 0 | * | 47 | 0 | 0 | 0 | 0 | * |
| Spring disk (T) | 0 | 0 | * | 0 | 0 | * | 0 | 0 | 0 | 46 | 0 | * |
| CCOMM | | | | | | | | | | | | |
| Fall chisel | 206 | 206 | * | 0 | 193 | * | 0 | 0 | 0 | 0 | 0 | * |
| Fall chisel (C) | 0 | 0 | * | 206 | 13 | * | 0 | 0 | 0 | 0 | 0 | * |
| Spring chisel (C) | 0 | 0 | * | 0 | 0 | * | 140 | 226 | 233 | 37 | 120 | * |
| Permanent pasture | 0 | 0 | * | 0 | 0 | * | 73 | 35 | 28 | 154 | 141 | * |

* Indicates that all 1990 values are equal to 1985 values for the same level of restriction.
C Indicates contouring.
T Indicates terracing.

the acres planted in various rotations and tillage systems in study aggregate 8. Farm operations within this aggregate closely resemble those that occur in the Four-Mile Creek region.

Table 24 indicates that in the absence of soil loss restrictions, higher energy prices would cause farmers in this study aggregate to switch from continuous corn into corn-bean rotations, and to employ no-till planting operations for part of the land in the corn-bean rotation. Although farmers do adjust to rising energy prices, substitution possibilities for energy saving in production are quickly exhausted as implied by projected 1990 production practices that are identical with those obtained with projected 1985 prices.

To examine the pattern of farm production that would occur under alternate soil loss restrictions, holding energy prices constant, the first, fourth, seventh, and tenth columns in Table 24 can be consulted. A ten-ton limit is met by using no-till planting on a small proportion of continuous corn and corn-bean acres (the acres that are most erosive). Also, the land planted in the CCOMM rotation is now contoured.

A five-ton restriction requires a large increase in no-till planting. In addition, 66 thousand acres are taken out of the CCOMM rotation and put into permanent pasture. A small amount of land is taken out of continuous corn and put into the corn-bean rotation and into permanent pasture.

To meet the three-ton restriction on soil loss, 69 thousand acres must be terraced and either disked or chiseled in the spring. An additional 103 thousand acres is transferred out of CCOMM, and a total of 189 thousand acres are planted with no-till operations. It is apparent that at the three-ton limit almost all of the cropland in study aggregate 8 must be terraced or planted with no-till operations. If energy prices were to rise with a three-ton limit imposed on soil erosion, the same total number of acres would be planted with a no-till planter but all of this land would be in a corn-bean rotation. Since no-till planting is erosion-efficient as well as energy-efficient, 13 thousand acres could be removed from permanent pasture and planted in a CCOMM rotation.

Restrictive soil loss limits tend primarily to increase the amount of permanent pasture in the river basin and to induce a switch to no-till planting, contouring, and terracing for each individual rotation. The proportion of acres of continuous corn to corn-beans remains relatively constant with constant prices. At a given soil loss limit, higher energy prices tend to eliminate continuous corn planting and increase the number of acres in corn-beans and corn-corn-oats-meadow-meadow rotations. In study aggregate 8 the combined effect of projected 1990 energy prices and a three-ton restriction induces the removal of 30 percent of the total land area from production and necessitates planting two-thirds of the total cropland with no-till operations.

Table 25 shows the acres planted in various rotations and tillage systems in study aggregate 8 under the subsidy policy. As with the soil loss restrictions policy, higher subsidy levels cause a decrease in erosion by inducing a switch to contouring and no-till planting and an increase in permanent pasture. It is important to note that

Table 25. Total Area in Various Rotations and Tillage Systems (in 1000s of acres) for Soil Aggregate 8 With Subsidies

| | $1/T subsidy | | | $6/T subsidy | | | $10/T subsidy | | | $14/T subsidy | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 |
| Continuous corn | | | | | | | | | | | | |
| Fall chisel | 63 | 0 | * | 63 | 0 | * | 63 | 0 | * | 0 | 0 | * |
| No-till | 18 | 0 | * | 0 | 0 | * | 0 | 0 | * | 63 | 0 | * |
| Corn-beans | | | | | | | | | | | | |
| Fall chisel | 126 | 189 | * | 126 | 189 | * | 126 | 0 | * | 0 | 0 | * |
| No-till | 36 | 54 | * | 0 | 0 | * | 0 | 189 | * | 126 | 189 | * |
| Fall chisel C | 0 | 0 | * | 91 | 0 | * | 47 | 0 | * | 0 | 0 | * |
| CCOMM | | | | | | | | | | | | |
| Fall chisel | 0 | 0 | * | 0 | 0 | * | 0 | 0 | * | 0 | 0 | * |
| Fall chisel C | 206 | 206 | * | 0 | 0 | * | 0 | 0 | * | 0 | 0 | * |
| Spring chisel C | 0 | 0 | * | 115 | 260 | * | 140 | 226 | * | 0 | 0 | * |
| Permanent pasture | 0 | 0 | * | 54 | 0 | * | 73 | 35 | * | 260 | 260 | * |

* Indicates that all 1990 values are equal to 1985 values for the same level of subsidy.

C Indicates contouring.

terracing does not occur even if a $14/ton subsidy is offered. In fact, the only terracing that takes place under the subsidy strategy is on study aggregate 7 when subsidy levels reach $10/ton.

Higher energy price levels again induce a shift from continuous corn to corn-bean rotations. From Table23 it is clear that at the $1/ton and $14/ton subsidy levels, higher energy prices induce an increase in erosion in study aggregate 8. This occurs because at those subsidy levels the switch to corn-beans rotations is not offset by large increases in the CCOMM rotations and/or large increases in no-till operations.

## G. Farm-Level Impacts on Net Income

Table 26 shows the decreases in net income of the representative farms that is caused by rising energy prices and the imposition of erosion limits. It indicates that at 1978 prices a ten-ton limit can be met with little loss in net income, and that only farms in three of the study aggregates will suffer any net income loss.

The per farm cost of meeting the tighter restrictions is considerably higher in soil aggregates 6-9. The loss in net income involved in meeting the five-ton limit at 1978 prices ranges from $1,736 per farm in aggregate 9 to $8,668 per farm in aggregate 6. At the three-ton limit with 1978 prices a representative farm may suffer a decrease in net income as high as $13,636 in aggregate 6, and at this level of restriction farmers in five of the nine study aggregates will experience some decrease in net income. The net income of farmers in some study aggregates is not altered by the imposition of soil loss limits since erosion on these soils

Table 26. Per Farm 1978 Baseline Net Income and Decrease in Per Farm Net Income From 1978 Baseline Solution

| Study aggregate | Per farm income | No restrictions | | | 10 tons/farm ave. | | | 5 tons/farm ave. | | | 3 tons/farm ave. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 |
| 1 | $43,838 | | $5,996 | $10,135 | * | * | * | * | * | * | * | * | * |
| 2 | 46,780 | | 6,618 | 11,006 | * | * | * | * | * | * | * | * | * |
| 3 | 44,521 | | 6,190 | 10,203 | * | * | * | * | * | * | 55 | 6,228 | 10,214 |
| 4 | 50,936 | | 7,068 | 11,557 | * | * | * | * | * | * | * | * | * |
| 5 | 40,826 | | 5,564 | 9,154 | * | * | * | * | * | * | * | * | * |
| 6 | 43,142 | | 5,096 | 8,531 | 838 | 5,815 | 9,163 | 8,668 | 12,714 | 15,380 | 13,636 | 17,630 | 20,187 |
| 7 | 48,537 | | 5,178 | 8,707 | 25 | * | * | 4,706 | 10,209 | 13,645 | 9,716 | 14,881 | 18,099 |
| 8 | 52,393 | | 4,905 | 8,153 | 57 | 4,907 | 8,155 | 5,434 | 9,558 | 12,261 | 13,605 | 17,649 | 20,156 |
| 9 | 62,290 | | 6,369 | 10,471 | * | * | * | 1,736 | 8,154 | 12,218 | 9,987 | 15,065 | 18,247 |

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* Indicates that the per farm decrease in net income from the baseline solution equals the "no restrictions" value.

is less in the baseline solution than the loss limit.

The decrease in net income is much greater, of course, in the presence of higher energy prices. If projected 1990 energy prices prevail, then a three-ton soil loss restriction may cause a decrease of up to $20,187 in per farm net income (or as much as a 47 percent decrease in net income).

Table 27 shows the total per farm subsidy receipts in the various study aggregates at alternate subsidy and energy price levels. The table indicates a wide difference in amount of subsidy income received among the study aggregates. At the $1/ton level with 1978 prices farmers in three study aggregates will receive no subsidy payments, while subsidy income ranges from $490 to $87,530 per farm at the $14/ton level. The highest subsidy payments are associated with erosion abatement on the most erosive soils. In particular, subsidy payments of $2,967, $25,050, $62,522, and $87,530 per farm in study aggregate 6 are associated with subsidy levels of $1/ton, $6/ton, $10/ton, and $14/ton, respectively, at constant 1978 energy prices. With a baseline per farm net income of $43,142 in study aggregate 6, the subsidy payments correspond to 7 percent, 58 percent, 145 percent, and 203 percent of baseline per farm net income. The impact of rising energy prices on per farm subsidy receipts varies for the same reasons that the effect of higher energy prices on study aggregate erosion varies.

### H. Conclusions and Caveats

The incremental cost of abatement of soil erosion under the soil loss restriction policy at 1978 prices and 1985 projected energy prices

Table 27. Total Per Farm Subsidy at Alternative Subsidy and Energy Price Levels in the Various Study Aggregates.

| Study | $1/T subsidy | | | $6/T subsidy | | | $10/T subsidy | | | $14/T subsidy | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| aggregate | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 | 1978 | 1985 | 1990 |
| 1 | 0 | $12 | $12 | $245 | $72 | $72 | $408 | $120 | $120 | $571 | $207 | $207 |
| 2 | 8 | 20 | 23 | 524 | 2452 | 2452 | 4454 | 4087 | 4087 | 6236 | 5722 | 5722 |
| 3 | 356 | 315 | 352 | 2859 | 4024 | 4251 | 4251 | 9939 | 9939 | 12,153 | 14,507 | 14,507 |
| 4 | 0 | 51 | 25 | 478 | 2454 | 2454 | 4455 | 4455 | 4090 | 6238 | 6238 | 5725 |
| 5 | 0 | 6 | 6 | 137 | 42 | 42 | 350 | 350 | 72 | 490 | 490 | 100 |
| 6 | 2967 | 3290 | 3290 | 25,771 | 27,050 | 27,050 | 62,522 | 62,313 | 62,313 | 87,530 | 87,238 | 87,238 |
| 7 | 1149 | 933 | 923 | 8120 | 7778 | 7778 | 25,600 | 27,116 | 26,834 | 38,076 | 38,076 | 37,961 |
| 8 | 1652 | 1645 | 1645 | 12,122 | 12,512 | 12,512 | 23,223 | 25,080 | 25,080 | 52,994 | 52,818 | 52,818 |
| 9 | 1112 | 1078 | 1078 | 7334 | 7546 | 7732 | 14,079 | 17,266 | 17,266 | 24,445 | 24,172 | 24,172 |

is shown by Figure 4. Figure 5 gives the marginal cost of abatement curves under the subsidy program at 1978 and 1985 projected prices. For the river basin as a whole, higher energy prices tend to reduce soil erosion by causing the adoption of less erosive tillage practices (as long as per ton subsidies for abatement are not above a specific level). The marginal cost of abatement curve for 1985 prices will lie above the 1978 curve. That is, the incremental cost of reducing soil erosion by a specified amount will be higher if projected 1985 energy prices prevail. If a marginal benefits of abatement curve were known and depicted in either figure, it would be clear that higher energy prices would cause the socially desirable level of NPS pollution to decrease (assuming the marginal benefits of abatement curve is not completely inelastic).

The overall policy implications of the study are that higher energy prices will enhance the effectiveness of soil loss restriction policies--bringing about a larger reduction in soil erosion and fertilizer use; but as the relative price of energy rises, the cost of abating an additional unit of soil erosion will rise. Unfortunately, rising energy prices will cause an even greater decrease in net farm income to be associated with a specific erosion limit than if energy prices were constant. The combination of higher energy prices and very restrictive soil loss limits may put a severe strain on the net incomes of some farmers.

Subsidies for erosion abatement will also reduce soil loss and fertilizer use, but the impact of rising energy prices on the

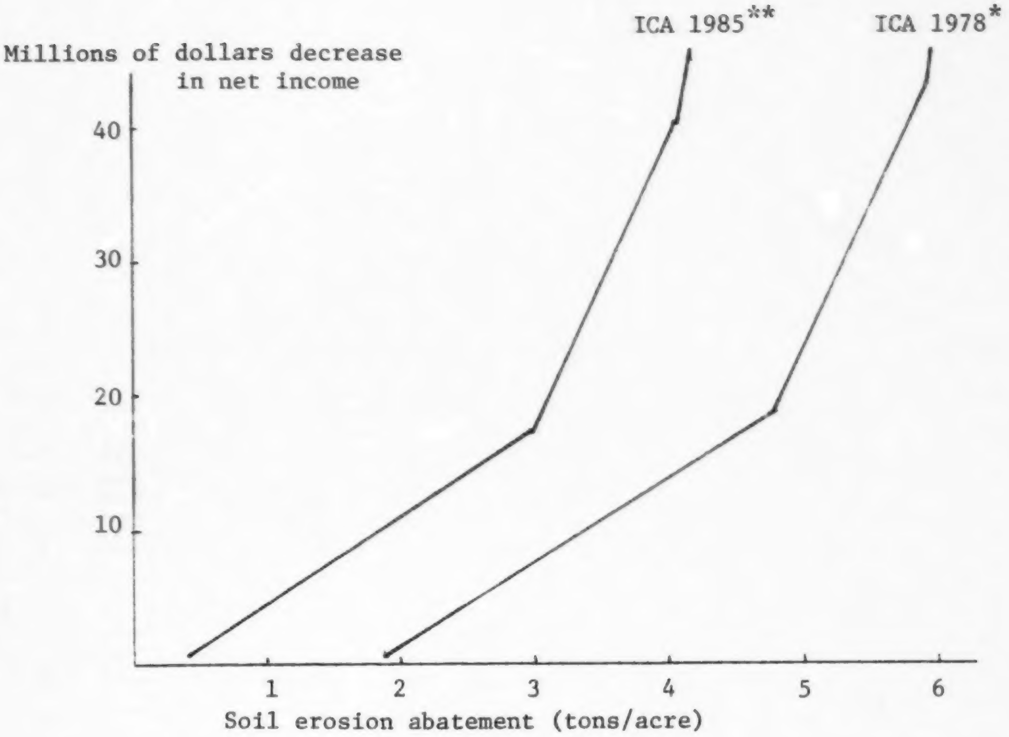

Figure 4. Incremental cost of abatement for soil loss restriction policy for Iowa River Basin.

*The ICA 1978 curve gives the marginal cost of abatement curve at 1978 energy prices.

**The ICA 1985 curve gives the marginal cost of abatement curve at projected 1985-relative energy prices. (An ICA 1990 curve would be identical to the ICA 1985 curve.)

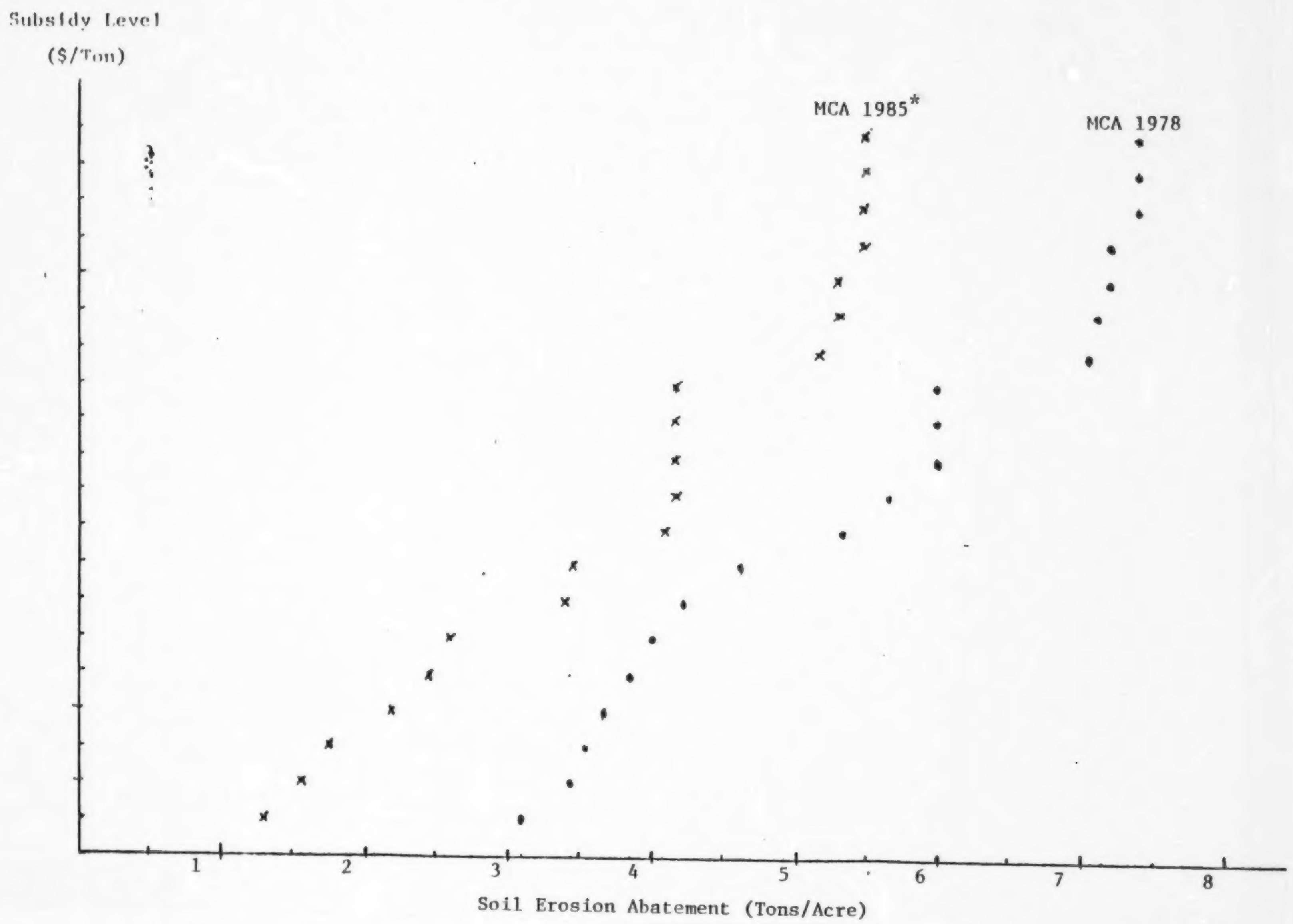

Figure 5. Marginal cost of abatement for subsidy policy for Iowa River Basin.

*An MCA 1990 curve would be almost identical to the MCA 1985 curve.

effectiveness of the policy is not unambiguous. At low subsidy levels it seems clear that rising energy prices will enhance the effectiveness of the subsidy policy in the river basin. However, if subsidy levels are high then rising energy prices may weaken the impact of abatement subsidy policy on soil erosion.

It is important to note that terracing does not play a very large role in erosion control under either policy accompanying rising energy prices. With an abatement subsidy policy in effect, terracing is not economically viable until the subsidies reach the $10/ton level, and then terracing appears in only one study aggregate. A three-ton soil loss restriction will force the adoption of terraces, but higher energy prices greatly reduce the number of acres terraced.

In the absence of any soil loss constraints, higher relative prices for energy will cause a reduction in soil erosion. The model predicts that erosion in the study area will decrease by almost two tons per acre over the next ten years if relative prices for energy follow the projected course. The effect of rising energy prices on soil erosion will be essentially the same as the imposition of a ten-ton per acre average soil loss limit on each farm in the river basin.

There are clear limitations to rising energy prices inducing a reduction in soil erosion with current farm technology. To reduce soil loss beyond the level induced by rising energy prices, an erosion control policy is necessary. However, as soil loss limits are made more restrictive (or higher abatement subsidies are offered) an increasing amount of cropland will be put into permanent pasture and net farm income will decrease (or subsidy payments will increase).

Potential shortcomings do exist in this analysis of the interaction between energy price increases and soil erosion control. Thus, caution should be exercised when interpreting these results.

First, the linear programming model may not reflect the actual substitution possibilities that exist between different energy inputs and between energy and other farm inputs in the study region. This problem was partially overcome by developing a comprehensive specification of the production activities available to the farmers.

Second, as relative energy prices rise, the development of new energy-efficient technology may be induced--especially by 1990. The present model assumes existing technology and may further underestimate substitution possibilities.

Third, the analysis postulates isolation from the supply and market adjustments that would be forthcoming in a general equilibrium framework as energy prices rise and other input prices change.

Fourth, the usual limitations of linear analysis are present.

Fifth, only two soil loss control policy options were considered in this analysis. Other choices, such as a tax on soil loss, practice-specific subsidies, and technical restrictions (e.g., limitations on tillage) may be viable alternatives but were not considered. Yet, abstracting from administration and enforcement costs, the subsidy for reduced soil loss is an economically-efficient alternative for achieving a social optimum. Also, the impacts of rising energy prices on soil loss are consistent between the alternatives considered and should be safely generalized to other policy options as well.

Finally, to say that soil loss restrictions or abatement subsidies reduce soil erosion by a particular amount is not the same as saying these policies will improve water quality by that amount. Two further lines of research must be pursued. A transport model must be developed that explicitly shows how particular quantities of soil enter the waterways and their impact on water quality. Then the transport model must be integrated with the farm production/soil loss programming model presented above.

# APPENDIX A

# FOUR MILE CREEK WATERSHED QUESTIONNAIRE

Iowa State University of Science and Technology Ames, Iowa 50011

Department of Economics

February 27, 1980

Dear Participant:

We are currently conducting a survey on farm production practices as they relate to soil conservation in the Four-Mile Creek Watershed. Our purpose is to determine how farmers in the watershed currently manage crop and livestock activities and how farmers would adjust their production activities if additional incentives were provided for soil loss control. We are also interested in quantifying the farmer's attitude toward risk to determine what impact this attitude has on the adoption of new crop production practices.

Given the nature of the information that is requested in this portion of the survey, we feel that it can best be done at your convenience. Although some of the questions may appear to overlap with data previously requested from you, it will be used for a different purpose or in a different context. Thus we would appreciate your cooperation in providing such information again.

There are five components to this questionnaire:

I. Machinery and Implement Inventory
II. Crop Management Practices
III. Livestock Management Practices
IV. Risk Attitudes
V. Miscellaneous Farm Questions

Please fill out each component of the questionnaire at your convenience. One of our field workers will make an appointment with you to pick-up the questionnaire between March 10 and March 24. When the field workers contact you for an appointment, please inform them of any problems you have had with the questionnaire.

If you have any questions or concerns while filling out the questionnaire, please call Michael Monson or James Shortle at (515)294-2333. Again, we appreciate your cooperation.

Sincerely,

John A. Miranowski

John A. Miranowski
Assistant Professor

JAM:sjb
Enclosure

## Part I: Machinery and Implement Inventory

At the bottom of this page and on the next is a list of different types of farm machinery and implements. Please indicate which of these you own, rent or hire, or borrow by placing a "✓" in the appropriate box to the right of the item. If you own the machine or implement, please estimate its age or model year in the "Age" column for that item. This estimate is not required for all items. Please indicate the horsepower of tractors and size of other implements in the appropriate space to the left of each item. If you have more than one of a particular piece of equipment, make note of that fact and record the appropriate information for each. Also indicate any major pieces of equipment that you feel are significant in your farming practice on the lines marked "Other" at the end of the next page, if not listed below.

| Machinery Type | | Size | Age (If Owned) | Own | Borrow | Rent/ Hire |
|---|---|---|---|---|---|---|
| Tractor(s): | Fuel Type | | | | | |
| Circle fuel type | gas/diesel | _____ Horsepower | __________ | | | |
| | gas/diesel | _____ Horsepower | __________ | | | |
| | gas/diesel | _____ Horsepower | __________ | | | |
| | | _____ Horsepower | __________ | | | |
| Tillage Equipment: | | | | | | |
| Moldboard plow | | _____bottoms _____inches | __________ | | | |
| Chisel plow | | _____feet | __________ | | | |
| Offset Disk | | _____feet | __________ | | | |
| Tandem Disk | | _____feet | __________ | | | |
| Field Cultivator | | _____feet | __________ | | | |
| Field Conditioner | | _____feet | __________ | | | |
| Stalk Chopper | | _____feet or rows | __________ | | | |
| Harrow | | _____feet | __________ | | | |

(Continued)

| Machinery Type | Size | Age (If Owned) | Own | Borrow | Rent/ Hire |
|---|---|---|---|---|---|
| Planter(s): | | | | | |
| Conventional Planter | _____rows _____inches | __________ | | | |
| Fertilizer/Insecticide attachments | | | | | |
| No-till Planter | _____rows _____inches | __________ | | | |
| Rotary Strip-till or Buffalo Planter | _____rows _____inches | __________ | | | |
| Grain Drill | _____feet | __________ | | | |
| Broadcast Seeder | | | | | |
| Weed Control: | | | | | |
| Rotary Hoe | _____feet or rows | | | | |
| Cultivator | _____rows | __________ | | | |
| Sprayer (mounted) | _____feet _____gal. | | | | |
| Sprayer (trailer) | _____feet _____gal. | | | | |
| High Clearance Sprayer | _____feet | | | | |
| Harvesting: | | | | | |
| Corn Picker | _____rows | | | | |
| Pull-type Combine | _____feet | | | | |
| Self-propelled Combine | _____model # | __________ | | | |
| Bean Head | _____feet | | | | |
| Corn Head | _____rows | | | | |
| Silage Harvester | _____rows | | | | |
| Gravity-Flow Wagons | _____(number) _____bu.@ | | | | |
| Box Wagons | _____(number) _____bu.@ | | | | |
| Fertilizing: | | | | | |
| Bulk Spreader | | | | | |
| Anhydrous Applicator | _____feet | | | | |
| Haying: | | | | | |
| Baler (square) | | | | | |
| Baler (round) | _____lbs. per bale | | | | |
| Stacker | _____Tons per stack | | | | |
| Other: | | | | | |
| __________ | _____ | __________ | | | |
| __________ | _____ | __________ | | | |
| __________ | _____ | __________ | | | |

## Part II: Crop Management Practices

This part of the survey is composed of three sections.

1. The first section contains questions about how you would choose field operations for alternative corn and soybean rotations.

2. The second section contains questions about crop yields from corn and soybean rotations.

3. The third section contains miscellaneous questions about cropping practices.

### Section One of Part II.

This section of the survey is designed to provide information about how you manage the crops you grow on level and hilly fields. Below are four tables which ask for information about:

1. Your tillage practices before planting
2. Your tillage practices for weed control
3. The approximate dates of these operations
4. The number of times each is performed
5. Your herbicide application practices.

There is a table for each of the following crop rotations:

1. Continuous corn
2. Corn after soybeans
3. Corn after grass or hay
4. Soybeans after corn

Choose the table or tables for the rotation or rotations you are normally engaged in. In filling out these tables include all tillage operations you normally perform in growing the crop. Our interest is in general management practices so that you need not be specific about your different fields.

To facilitate your responses, the following example table is given for a continuous corn rotation.

EXAMPLE: Continuous Corn Table.

| | Level Fields | | | Hilly Fields | | |
|---|---|---|---|---|---|---|
| | Operation | Times | Approx. date | Operation | Times | Approx. date |
| Tillage before planting (Begin in fall of previous year) | Disk<br>Moldboard Plow<br>Disk<br>Harrow | 1<br>1<br>1<br>1 | November<br>April<br>April<br>April | Chop Stalks<br>Chisel Plow<br>Disk | 1<br>1<br>2 | November<br>November<br>April |
| Approximate date of planting | | | May 1-5 | | | May 1-5 |
| tillage for weed control | Rotary Hoe<br>Cultivate | 1<br>2 | May 15-20<br>June | Rotary Hoe<br>Cultivate | 1<br>2 | May 15-20<br>June |
| Herbicide application | Incorporate<br>Postemerge | | Late April<br>Mid June | Incorporate<br>Postemerge | | Late April<br>Mid June |

1. Continuous Corn Table.

|  | Level Fields |  |  | Hilly Fields |  |  |
|---|---|---|---|---|---|---|
|  | Operation | Times | Approx. date | Operation | Times | Approx. date |
| Tillage before planting (Begin in fall of previous year) |  |  |  |  |  |  |
| Approximate date of planting | ☒ | ☒ |  | ☒ | ☒ |  |
| tillage for weed control |  |  |  |  |  |  |
| Herbicide application |  |  |  |  |  |  |

2. Corn After Soybeans Table.

| | Level Fields | | | Hilly Fields | | |
|---|---|---|---|---|---|---|
| | Operation | Times | Approx. date | Operation | Times | Approx. date |
| Tillage before planting (Begin in fall of previous year) | | | | | | |
| Approximate date of planting | | | | | | |
| tillage for weed control | | | | | | |
| Herbicide application | | | | | | |

3. Corn After Grass or Hay Table.

| | Level Fields | | | Hilly Fields | | |
|---|---|---|---|---|---|---|
| | Operation | Times | Approx. date | Operation | Times | Approx. date |
| Tillage before planting (Begin in fall of previous year) | | | | | | |
| Approximate date of planting | X | X | | X | X | |
| tillage for weed control | | | | | | |
| Herbicide application | | | | | | |

4. Soybeans After Corn Table.

| | Level Fields | | | Hilly Fields | | |
|---|---|---|---|---|---|---|
| | Operation | Times | Approx. date | Operation | Times | Approx. date |
| Tillage before planting (Begin in fall of previous year) | | | | | | |
| Approximate date of planting | | | | | | |
| tillage for weed control | | | | | | |
| Herbicide application | | | | | | |

## Section Two of Part II

In columns A and B of the table below (page 10) are listed combinations of rotations and tillage practices. For each combination please give the information requested in columns C, D, and E. While you may not have had experience on your farm with each of the listed tillage practices, please give your best estimate of the following:

1. Estimated Yield: For estimated yields, indicate the average per acre yield you would expect to have on your farm during an average or normal farm year.
2. Yield Range: The actual yield obtained during average or normal years may be more or less than the average yield you expect during normal years. To indicate the range of the average or normal year crop yield, please indicate in the "+" column of "D" how many additional bushels your yield might reasonably be above the average specified in column "C". Indicate in the "-" column of "D" how many fewer bushels your yield might be below the average amount of a normal year. The numbers you place in "+" amd "-" columns need not be equal.
3. Risk Ranking: The scale at the bottom of the table runs from one to eleven. Using a number from this scale please indicate in column "E" your evaluation of the relative "riskiness" of the alternative crop rotation-tillage practice combinations. This ranking shows how risky you feel these alternatives are relative to each other on your farm.

Definition of Tillage Practices:

| | |
|---|---|
| Fall Moldboard: | The crop ground is moldboard plowed in the fall following harvest. |
| Fall Chisel: | The crop ground is chisel plowed in the fall following harvest. |
| Spring Chisel: | The crop ground is chisel plowed in the spring before planting time. |
| Spring Disk: | No moldboard or chisel plow is used. A disk is used as primary tillage in the spring. |
| No-till: | A no-till planter is used. It is assumed that planting is done on the contour with a no-till planter. There is no tillage of the soil prior to planting. |
| Straight row: | Planting is done in typical or straight fashion. No effort is made to follow the lay of the land. |
| Contour: | Planting is done to follow the lay or "contour" of the land. In determining yield estimates for contour planting, consider losses due to point rows, additional turning, etc. |

| A. Tillage | B. Crop(s) | C. Estimated Yield | D. Range | | E. Risk Rating |
|---|---|---|---|---|---|
| Fall Moldboard | Continous Corn | | + | - | |
| Straight row | Corn/ | | + | - | |
| | Soybeans | | + | - | |
| Fall Chisel | Continous Corn | | + | - | |
| Straight row | Corn/ | | + | - | |
| | Soybeans | | + | - | |
| Spring Chisel | Continous Corn | | + | - | |
| Straight row | Corn/ | | + | - | |
| | Soybeans | | + | - | |
| Spring Disk | Continous Corn | | + | - | |
| Straight row | Corn/ | | + | - | |
| | Soybeans | | + | - | |
| Fall Moldboard | Continous Corn | | + | - | |
| Contour | Corn/ | | + | - | |
| | Soybeans | | + | - | |
| Fall Chisel | Continous Corn | | + | - | |
| Contour | Corn/ | | + | - | |
| | Soybeans | | + | - | |
| Spring Chisel | Continous Corn | | + | - | |
| Contour | Corn/ | | + | - | |
| | Soybeans | | + | - | |
| Spring Disk | Continous Corn | | + | - | |
| Contour | Corn/ | | + | - | |
| | Soybeans | | + | - | |
| No-till | Continous Corn | | + | - | |
| | Corn/ | | + | - | |
| | Soybeans | | + | - | |

| | Less Risky | | | | | | | | | More Risky |
|---|---|---|---|---|---|---|---|---|---|---|
| Risk Rating: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |

Section III of Part II.

1. For the following crops, give an estimated yield and range similar to the questions above. Think of your own current tillage practices for each crop.

| Crop |  | Estimated Yield | Range |  |
|---|---|---|---|---|
| Corn following one-year meadow |  |  | + | - |
| Corn following two-year meadow |  |  | + | - |
| Oats after Corn: | Oats |  | + | - |
|  | Straw | Tons or bales | + | - |
| First-year Meadow |  |  | + | - |
| Second-year Meadow |  |  | + | - |

2. You may have some part of your farm that has been terraced or could be terraced. Considering point rows, following the terrace shape, turning space, etc., and the long-term benefits, if any, of terracing, estimate the impact of terracing on yields from that ground.

| Crop | Yield Change | (✓) |  |
|---|---|---|---|
| Continous Corn | _____ bu. | ___ Increase | ___ Decrease |
| Corn after Soybeans | _____ bu. | ___ Increase | ___ Decrease |
| Soybeans after Corn | _____ bu. | ___ Increase | ___ Decrease |

3. The following table lists three types of insect control (primarily for corn rootworm). Estimate your corn yield for each type used on continous corn and corn after soybeans. Establish a range for that yield as in previous questions.

| Crop | Insect Control | Corn Yield | Range |  |
|---|---|---|---|---|
| Continous Corn | Soil Insecticide |  | + | - |
|  | Pest Management |  | + | - |
|  | No Treatment |  | + | - |
| Corn after Soybeans | Soil Insecticide |  | + | - |
|  | Pest Management |  | + | - |
|  | No Treatment |  | + | - |

4. The prices you receive for your grain products can be highly variable. What are your expectations with regard to prices for the grain you produce? Please give an expected or estimated price and some range for that price that you would expect for the coming year.

| Grain | Price | Range |  |
|---|---|---|---|
| Corn | $ /bu. | + | - |
| Soybeans | $ /bu. | + | - |
| Oats | $ /bu. | + | - |

## Part III: Livestock Management Practices

Please answer the following questions:

1. Do you regularly raise livestock for sale?
   a. ____ yes (go to question 2.)
   b. ____ no (you have completed the livestock questionaire)

2. Please indicate which of the following types of livestock activities you are regularly engaged in and the approximate numbers of each for last year:

| Letter Code | Type | (✓) | | |
|---|---|---|---|---|
| A. | Farrow-to-Finish | ____ | ________ | litters |
| B. | Raising Feeder Pigs | ____ | ________ | head |
| C. | Finishing Feeder Pigs | ____ | ________ | head |
| D. | Cow-calf Herd | ____ | ________ | cows |
| E. | Calf Feeding | ____ | ________ | head |
| F. | Steer Finishing | ____ | ________ | head |
| G. | Dairy Cattle | ____ | ________ | head (____ milk grade, ____ lbs. per cow) |
| H. | Other: ________ | ____ | ________ | |
| I. | ________ | ____ | ________ | |

WHEN ASKED FOR LIVESTOCK TYPE IN THE FOLLOWING QUESTIONS, PLEASE USE THE LETTER CODE TO THE LEFT OF THE TYPE IN QUESTION 2. (e.g., "G." for dairy cattle)

3. Do you regularly maintain acres of pasture, meadow, or oats for the grazing, bedding, or feeding of livestock? Please indicate your response below.

| Number | | | | Letter Code |
|---|---|---|---|---|
| ________ | Acres of | ________ | for | ____ |
| ________ | Acres of | ________ | for | ____ |
| ________ | Acres of | ________ | for | ____ |
| ________ | Acres of | ________ | for | ____ |
| ________ | Acres of | ________ | for | ____ |

4. If you feed cattle, please indicate which of the following types of feeds you normally use:

| | | Letter Code |
|---|---|---|
| Corn Silage | for | ____ |
| Corn Silage with Corn | for | ____ |
| Hay with Corn | for | ____ |
| Corn Silage with Stover | for | ____ |
| Stover, Hay, and Corn | for | ____ |

(Continued)

5. Please indicate how you handle animal waste and disposal.

| System | Letter Code(s) | Waste Disposal (Check method) | |
|---|---|---|---|
| Confinement pit | for _____ | surface applied | _____ |
| Confinement lagoon | for _____ | subsurface incorporation | _____ |
| Open feed lot | for _____ | other: ______________ | _____ |
| Other ______________ | for _____ | | |

6. Do you normally maintain your livestock levels above some minimum number? If not, proceed to the next question. If you do have some minimum levels, please indicate the reasons for this minimum with a "v" below.

| Reason | (✓) |
|---|---|
| Personal enjoyment from raising animals | _____ |
| Provides for risk diversification | _____ |
| Provides employment for off-crop season labor | _____ |
| Other (Please specify): ______________<br>______________________________ | _____ |

Please indicate what types of livestock you maintain such minimum levels for with the letter code for that type and the approximate minimum level you wish to maintain.

| Type (Letter Code) | Minimum Level |
|---|---|
| _____ | ____________ |
| _____ | ____________ |
| _____ | ____________ |
| _____ | ____________ |
| _____ | ____________ |

(Continued)

7. Is there some maximum number of each type of livestock that you raise which you choose not to or cannot exceed? If so, please indicate those livestock activities by their letter code and the maximum number. Also from the list below, select the constraint or reason that imposes this maximum restriction with the appropriate number in the "Constraint" column for each livestock type.

| Livestock Type | Maximum Level | Constraint |
|---|---|---|
| ____ | __________ | ____ |
| ____ | __________ | ____ |
| ____ | __________ | ____ |
| ____ | __________ | ____ |
| ____ | __________ | ____ |

List of Constraints

1. Time
2. Land
3. Facilities
4. Do not enjoy

5. Riskiness
6. Other ____________

8. The prices you receive for your livestock products can be highly variable. What are your expectations with regard to prices for the livestock products you produce? Please give an expected or estimated price and some range for that price that you would expect for the coming year for the products you raise.

| Livestock Type | Price | Range | |
|---|---|---|---|
| Finished cattle | $ /cwt. | + | - |
| Market hogs | $ /cwt. | + | - |
| Feeder pigs | $ /head | + | - |
| Calves | $ /cwt. | + | - |
| Feeder cattle | $ /cwt. | + | - |
| Milk | $ /cwt. | + | - |
| Other: | $ | + | - |

## Part IV: Risk Attitudes

The following three sets of questions are designed to develop information about how you perceive risk and how you might make decisions under conditions that involve risk.

1.) Think of yourself as being faced with the following decision regarding the operation of your farm. You are considering an addition to or adjustment in one of your enterprises (e.g., a new technique in corn production; a new or expanded livestock operation; a new crop variety).

The addition or adjustment provides a positive but risky amount of income. Two income outcomes are possible and each outcome is equally likely (i.e., a 50/50 chance of obtaining the higher or lower income).

In the following questions you are given the risky enterprise income outcomes for your farm. Indicate which levels of certain or sure income you would prefer over the risky income alternative by placing a "✓" in the appropriate boxes below the certain income choices. Start with the highest certain income and select all those that you would prefer to the risky enterprise.

Example:

| | Certain Income Choices | | | | | | |
|---|---|---|---|---|---|---|---|
| Risky Choice | $2500 | $3000 | $3500 | $4000 | $4500 | $5000 | $5500 |
| $6000<br>or $2000 | | | ✓ | ✓ | ✓ | ✓ | ✓ |

In this example, the farmer would choose a sure or certain income of $3500 or more to the risky enterprise which provides an equally likely income of either $6000 or $2000.

Note that when making your decisions, there are no correct answers. Rather your choices indicate only your attitudes toward risk when you are making a choice between a risky addition or adjustment in your farm plan and a sure or certain income.

Additions to or Adjustments in Farm Income:

(Check preferred certain incomes starting from highest certain alternative)

(1)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Certain Income Choices | | | | | | | | |
| Risky Choice | $3500 | $4000 | $4500 | $5000 | $5500 | $6000 | $6500 | $7000 | $7500 |
| $8000<br>or $3000 | | | | | | | | | |

(2)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Certain Income Choices | | | | | | | | |
| Risky Choice | $5500 | $6000 | $6500 | $7000 | $7500 | $8000 | $8500 | $9000 | $9500 |
| $10000<br>or $5000 | | | | | | | | | |

(3)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Certain Income Choices | | | | | | | | |
| Risky Choice | $8500 | $9000 | $9500 | $10000 | $10500 | $11000 | $11500 | $12000 | $12500 |
| $13000<br>or $8000 | | | | | | | | | |

(4)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Certain Income Choices | | | | | | | | |
| Risky Choice | $12500 | $13000 | $13500 | $14000 | $14500 | $15000 | $15500 | $16000 | $16500 |
| $17000<br>or $12000 | | | | | | | | | |

(5)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Certain Income Choices | | | | | | | | |
| Risky Choice | $14500 | $15000 | $15500 | $16000 | $16500 | $17000 | $17500 | $18000 | $18500 |
| $19000<br>or $14000 | | | | | | | | | |

(6)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Certain Income Choices | | | | | | | | |
| Risky Choice | $18500 | $19000 | $19500 | $20000 | $20500 | $21000 | $21500 | $22000 | $22500 |
| $23000<br>or $18000 | | | | | | | | | |

(7)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Certain Income Choices | | | | | | | | |
| Risky Choice | $3500 | $4500 | $5500 | $6500 | $7500 | $8500 | $9500 | $10500 | $11500 |
| $12000<br>or $3000 | | | | | | | | | |

(8)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Certain Income Choices | | | | | | | | |
| Risky Choice | $10500 | $11500 | $12500 | $13500 | $14500 | $15500 | $16500 | $17500 | $18500 |
| $19000<br>or $10000 | | | | | | | | | |

2.) Now consider yourself in a position to develop your overall farm plan. Your plan determines your farm income for the entire year. The plan is risky in that it has two equally likely income outcomes (i.e., a 50/50 chance of obtaining the higher or lower income).

In the following questions you are given the risky farm plan with the two possible income levels for your entire farm. Indicate which levels of certain or sure income you would prefer to the risky income plan by placing a "✓" in the appropriate boxes below the certain income choices. Start with the highest certain income and select those that you would prefer to the risky plan.

Example:

| | Certain Income Choices | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Risky Choice | $16500 | $17000 | $17500 | $18000 | $18500 | $19000 | $19500 | $20000 | $20500 |
| $21000<br>or $16000 | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

In this example, the farmer would choose a sure or certain income of $17000 or more to the risky overall farm plan that has two possible income outcomes of $21000 or $16000.

Note that when making your decisions, there are no correct answers. Rather your choices indicate only your attitude toward risk when you are making a choice between a risky plan for your entire farm and a certain or sure income.

Entire Farm Income:

(Check preferred certain incomes starting from the highest certain alternative)

| | | Certain Income Choices | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Risky Choice | $8500 | $9000 | $9500 | $10000 | $10500 | $11000 | $11500 | $12000 | $12500 |
| (1) | $13000<br>or $8000 | | | | | | | | | |

| | | Certain Income Choices | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Risky Choice | $12500 | $13000 | $13500 | $14000 | $14500 | $15000 | $15500 | $16000 | $16500 |
| (2) | $17000<br>or $12000 | | | | | | | | | |

| | | Certain Income Choices | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Risky Choice | $16500 | $17000 | $17500 | $18000 | $18500 | $19000 | $19500 | $20000 | $20500 |
| (3) | $21000<br>or $16000 | | | | | | | | | |

| | | Certain Income Choices | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Risky Choice | $20500 | $21000 | $21500 | $22000 | $22500 | $23000 | $23500 | $24000 | $24500 |
| (4) | $25000<br>or $20000 | | | | | | | | | |

| | | Certain Income Choices | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Risky Choice | $24500 | $25000 | $25500 | $26000 | $26500 | $27000 | $27500 | $28000 | $28500 |
| (5) | $29000<br>or $24000 | | | | | | | | | |

| | | Certain Income Choices | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Risky Choice | $28500 | $29000 | $29500 | $30000 | $30500 | $31000 | $31500 | $32000 | $32500 |
| (6) | $33000<br>or $28000 | | | | | | | | | |

| | | Certain Income Choices | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Risky Choice | $15000 | $16000 | $17000 | $18000 | $18500 | $19000 | $20000 | $21000 | $22000 |
| (7) | $25000<br>or $12000 | | | | | | | | | |

| | | Certain Income Choices | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Risky Choice | $22000 | $24000 | $25000 | $26000 | $26500 | $27000 | $28000 | $29000 | $31000 |
| (8) | $34000<br>or $19000 | | | | | | | | | |

3.) Years of experience may lead a farmer to expect some income level from his farming operation, but these years of experience also indicate that the actual income he receives may be higher or lower than his expectations for any year. Even the most careful budgeting does not assure a certain level of income, and it doesn't do much good to fill the elevator, stockyard, or dinner plate with profitable budgets. The following questions are designed to establish your attitude about flucuations in your farm income:

a. Three farmers are discussing their prospects for next year. Farmer A has been making about $15000 a year. In normal years , he sometimes makes $17000; other times he makes as low as $12000. Farmer B has also been making about $15000 a year. In normal years he makes as much as $18000 and as low as $13000. Farmer C expects to make $17000, and his range is $19000 and $15000. Remembering that these are normal years, how would you describe your farm income situation in the same manner?

| | A | B | C | Your Farm Income |
|---|---|---|---|---|
| High Income Range | $17000 | $18000 | $19000 | $________ |
| Expected Income | $15000 | $15000 | $17000 | $________ |
| Low Income Range | $12000 | $13000 | $15000 | $________ |

The farmers discuss other income opportunities. The question arises: "How much sure or certain income would you require in place of your current income situation?" Farmer A would trade his present farm income situation for a sure $16000. Farmer B would require only $14000. Farmer C would trade for a sure income of $16500. What would be your response based on the income range you listed above?

| | A | B | C | Your Response |
|---|---|---|---|---|
| Certain Income | $16000 | $14000 | $16500 | $________ |

b. Rarely are we given the opportunity to see just how much happiness we can stand. More often, we find how much of a bad thing we can put up with. The three farmers discuss this matter with regard to their income ranges. Given their expected incomes from the previous question, the farmers arrive at minimum low and high incomes they could accept. Farmer A would let his low income drop to $10000 and his high income to $16000. Farmer B would let his low income fall only to $12000 and his high income to $17000. Farmer C could decrease his low income to $11000 and his high income to $18000. It is reasonable for some farmers to have no concern with the low income range. They would let it fall to $0. The responses of the three farmers are listed below. What would be the minimum high and low income you would allow based on your expected income from the previous question?

| | A | B | C | Your Response |
|---|---|---|---|---|
| Minimum High Income | $16000 | $17000 | $18000 | $________ |
| Expected Income (from a.) | $15000 | $15000 | $17000 | $________ |
| Minimum Low Income | $10000 | $12000 | $11000 | $________ |

It is likely that these responses would change as expected income rose or fell. Please establish minimum high and low income values for one-half and twice your current expected income.

| | One-Half | Twice |
|---|---|---|
| Minimum High Income | $________ | $________ |
| Expected Income | ½ × Current | 2 × Current |
| Minimum Low Income | $________ | $________ |

c. New techniques and innovations may change a farm's income situation such as it is described in earlier questions. Imagine a new technique that does not change expected income. However, it does increase the high income range by $1000. Unfortunately, it also decreases the low income range. Farmer A would adopt this new technique if it dropped his low income by $1500 or less. Farmer B would use this new technique only if it dropped his low income by $500 or less. Farmer C would adopt the new technique even if it dropped his low income by $2000. Given your expected income, what is the maximum decrease in your low income you would allow to adopt a new technique that increases your high income by $1000?

| | A | B | C | Your Response |
|---|---|---|---|---|
| Increase in High Income | +$1000 | +$1000 | +$1000 | +$1000 |
| Maximum Decrease in Low Income | -$1500 | -$500 | -$2000 | -$________ |

d. Imagine a new technique that does not affect expected farm income. However, it does increase the low income range of a farm income situation as described in earlier questions by $1000. Unfortunately it decreases the high income range as well. Farmer A would adopt this technique if it dropped his high income by less than $500. Farmer B would not adopt the technique if it lowered his high income range. Farmer C would use the new technique if it decreased his high income by less than $1500. Given your expected income, what is the maximum decrease in your high income you would accept for a $1000 increase in your low income?

| | | | | |
|---|---|---|---|---|
| Maximum Decrease in High Income | -$500 | -$0 | -$1500 | -$________ |
| Increase in Low Income | +$1000 | +$1000 | +$1000 | +$1000 |

## Part V: Miscellaneous Farm Questions

The following questions pertain to information about grain drying and storage, energy use, supply sources, etc.

1. How much on-farm storage do you have for grain? __________ bu.
2. What method do you use to dry corn? (please check)

   ___ continous flow dryer

   ___ batch bin

   ___ low temperature dryer

   ___ Other: _____________
3. What is the typical moisture content of your corn at harvest? _____%
4. Please estimate the amount of each fuel you used for your farming operation last year:

   Gasoline __________ gal.

   Diesel Fuel __________ gal.

   Liquid Propane __________ gal.
5. How much storage for fuel do you have?

   Gasoline __________ gal.

   Diesel Fuel __________ gal.

   Liquid Propane __________ gal.
6. Where do you purchase most of the following items? Please write in the business name.

   Fuels _________________________

   Pesticides _________________________

   Fertilizers _________________________

   Farm Equipment _________________________
7. If you desired to do some contour planting, would your present planter be suitable? (Please check)

   ___ Yes

   ___ No
8. What is the manufacturer's name of your current planter? ____________________

9.) How do you apply herbicides? To answer, please write "band" or "broadcast" in the pre-emerge or post-emerge blanks below or the implement used to incorporate pre-plant herbicide when responding to this question.

| | Pre-Plant Incorporated | Pre-Emerge | Post-Emerge |
|---|---|---|---|
| Continuous Corn | ________________ | ________________ | ________________ |
| Corn after soybeans | ________________ | ________________ | ________________ |
| Soybeans after corn | ________________ | ________________ | ________________ |

10.) Using the scale below:

| A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|
| 0% | 1-2% | 3-4% | 5-6% | 7-8% | 9-10% | 11-15% | 16-20% | 21%+ |

How much additional time does it take to perform operations on the contour than straight row ____________?

How much additional time does it take to perform operations on terraced land than straight row ______________?

Again, we appreciate your cooperation.

# APPENDIX B

## IOWA RIVER BASIN LINEAR PROGRAMMING MODEL

This section outlines in detail the structure of the linear programming model developed for the Iowa River Basin. As previously stated, the overall objective function of the model was constructed such that the baseline aggregate solution was the sum of the individual solutions from the nine independent soil aggregates.

$$Z = \sum_{i=1}^{9} R_i$$

The objective function in the solution of the i-th aggregate is given by

$$\begin{aligned} R_i = {} & P_C S_{Ci} + P_{SB} S_{Bi} + P_H S_{Hi} + P_O S_{Oi} + P_S S_{Si} + SF_i \, (\beta_S P_S - PSF_i) \\ & + CC_i \, (\beta_C P_B - PCC_i) + M_i \, (\beta_M P_M - PM_i) + HF_i \, (\beta_F P_{PP} - PHF_i) \\ & - \sum_{rtj}\sum\sum A_{rijt} \, (PC_{rijt} \, (P_F DF_{rijt} + P_{LP} LP_{rijtk} \\ & + P_N^K \, N_{rijtk}^P + P_P P_{rijtk} + P_K K_{rijtk} + P_I I_{rijt} + P_{Hr}^C H_{rijt}^C \\ & + P_{Hr}^B \, H_{rijt}^B) \end{aligned}$$

$i = 1, \ldots, 9$ study aggregates

$r = 1, 2, 3$ rotations*

$j = 1, \ldots, 5$ tillage systems

$t = 1, 2, 3$ practices

$k = 1, 2, 3$ fertilizer requirement levels where

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*See Appendix Table A for listings of "r", "t", and "j".

$S_{Ci}$ = corn sales in bushels of the i-th study aggregate;

$S_{Bi}$ = bean sales in bushels of the i-th study aggregate;

$S_{Hi}$ = hay sales in tons of the i-th study aggregate;

$S_{Oi}$ = oats sales in bushels of the i-th study aggregate;

$S_{Si}$ = straw sales in tons of the i-th study aggregate;

$P_C$ = per bushel price of corn;

$P_{SB}$ = per bushel price of beans;

$P_H$ = per ton price of hay;

$P_O$ = per bushel price of oats;

$P_S$ = per ton price of straw;

$SF_i$ = number of steers in the i-th study aggregate;

$CC_i$ = number of calves in the i-th study aggregate;

$M_i$ = number of dairy cows in the i-th study aggregate;

$HF_i$ = number of hog-litters in the i-th study aggregate;

$\beta_S P_S$ = sales price per steer;

$\beta_C P_B$ = sales price per calf;

$\beta_M P_M$ = milk price per cow;

$\beta_F P_{PP}$ = sales price per litter;

$PSF_i$ = cost per steer of steer feeding operation exclusive of feed;

$PCC_i$ = cost per calf of cow-calf operation exclusive of feed;

$PM_i$ = cost per cow of dairy operation exclusive of feed;

$PHF_i$ = cost per litter of hog-financing operation exclusive of feed;

$PC_{rijt}$ = per acre cost of the r-th rotation in the i-th study aggregate utilizing the j-th tillage system and t-th practice exclusive of chemical and fuel costs and exclusive of returns to farmland and management;

$DF_{rijt}$ = diesel fuel requirements per acre of the r-th rotation in the i-th study aggregate utilizing the j-th tillage system and t-th practice;

$LP_{rijtk}$ = propane gas requirements per acre of the r-th rotation in the i-th study aggregate utilizing the j-th tillage system and t-th practice;

$A_{rijt}$ = acres of rotation r in study aggregate i; utilizing the j-th tillage system and t-th practice;

$N^{P}_{rijtk}$ = nitrogen purchases per acre of the r-th rotation in the i-th study aggregate utilizing the j-th tillage system and t-th practice at the k-th level of nitrogen requirements;

$P_{rijtk}$ = phosphorus purchases per acre of the r-th rotation in the i-th study aggregate utilizing the j-th tillage system;

$K_{rijtk}$ = potassium purchases per acre of the r-th rotation in the i-th study aggregate utilizing the j-th tillage system and t-th practice at the k-th level of potassium requirement;

$I_{rijt}$ = insecticide requirements per acre of the r-th rotation in the i-th study aggregate utilizing the j-th tillage system and t-th practice;

$H^C_{rijt}$ = corn herbicide requirements per acre of the r-th rotation in the i-th study aggregate utilizing the j-th tillage system and t-th practice;

$H^B_{rijt}$ = bean herbicide requirements per acre of the r-th rotation in the i-th study aggregate utilizing the j-th tillage system and t-th practice;

$P_F$ = per gallon price of diesel fuel;

$P_{LP}$ = per gallon price of propane gas;

$P^K_N$ = per pound price of nitrogen;

$P_P$ = per pound price of phosphorus;

$P_K$ = per pound price of potassium;

$P_I$ = per acre price of insecticide;

$P^C_{Hr}$ = per acre price of corn herbicide of type r;

$P^B_{Hr}$ = per acre price of bean herbicide of type r.

The management problem is to choose, given price vectors for crops, livestock, and inputs, the combination of rotations, tillage systems, and levels of livestock activities that maximizes the value of $R_i$. The choice of crop production and livestock activities is made subject to the following constraints on land and crop output levels:[*]

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[*] Crop output levels were constrained to be sufficient to meet feed requirements and crop sales in the soil aggregate.

(1) $\sum\sum\sum_{rjt} A_{rijt} + PP_i \leq L_i$;

(2) $\sum\sum\sum_{rjt} Y^C_{rijtk} A_{rijt} - S_{Ci} - CC_i CCC_i - HF_i HFC_i$

$- SF_i\ SFC_i - M_i MC_i \geq 0$;

(3) $\sum\sum_{jt} Y^B_{r_B ijt} A_{r_B ijt} - S_{Bi} \geq 0$; where $r = r_B$ is the index of the corn-bean rotation;

(4) $\sum\sum_{jt} Y^O_{r_M ijt} A_{r_M ijt} - S_{Oi} - HF_i HFO_i \geq 0$, where $r = r_M$ is the index of the CCOMM rotation;

(5) $\sum\sum_{jt} Y^S_{r_M ijt} A_{r_M ijt} - S_{Si} - M_i MS_i \geq 0$;

(6) $\sum\sum_{jt} Y^H_{r_M ijt} (A_{r_M ijt} + PTM_i) - S_{Hi} - M_i MH_i \geq 0$;

(7) $PP_i + MTP_i - CC_i CCP_i \geq 0$;

(8) $PP_i - PTM_i \geq 0$;

(9) $\frac{2}{5} \sum\sum_{jt} A_{r_M ijt} - MTP_i \geq 0$;

(10) $\sum\sum\sum_{rij} A_{rijt} (N^R_{rijtk} - N^C_{rijtk} - N^P_{rijtk}) = 0$;

where

$Y^C_{rijtk}$ = corn yield per acre of the r-th rotation in the i-th study aggregate utilizing the j-th tillage system and t-th practice at the k-th level of nitrogen requirements;

$Y^B_{r_B ijt}$ = bean yield per acre of the corn-bean rotation in the i-th study aggregate utilizing the j-th tillage system and t-th practice;

$Y^O_{r_M ijt}$ = oats yield per acre of the CCOMM rotation in the i-th study aggregate utilizing the j-th tillage system and t-th practice;

$Y^H_{r_M ijt}$ = hay yield per acre of the CCOMM rotation in the i-th study aggregate utilizing the j-th tillage system and t-th practice;

$Y^S_{r_M ijt}$ = straw yield per acre of the CCOMM rotation in the i-th study aggregate utilizing the j-th tillage system and t-th practice;

$PP_i$ = acres of permanent pasture in the i-th study aggregate;

$L_i$ = total available acres in the i-th study aggregate;

$CCC_i$ = per cow-calf unit corn requirement;

$HFC_i$ = per litter corn requirement;

$SFC_i$ = per steer corn requirement;

$MC_i$ = per dairy cow corn requirement;

$HFO_i$ = per litter oats requirement;

$MS_i$ = per dairy cow straw requirement;

$MH_i$ = per dairy cow hay requirement;

$CCP_i$ = per cow-calf unit pasture requirement;

$MTP_i$ = "convert one acre of meadow to one acre of pasture";

$PTM_i$ = "convert one acre of pasture to one acre of meadow";

$N^R_{rijtk}$ = k-th level nitrogen requirements per acre of the r-th rotation in the i-th study aggregate utilizing the j-th tillage system and t-th practice;

$N^C_{rijtk}$ = nitrogen carryover per acre of the r-th rotation in the i-th study aggregate utilizing the j-th tillage system and t-th practice.

In addition to these restrictions, the following bounds on the choice of activity levels are also placed in the baseline solution:

(11) $M_i - \bar{M}_i^U \leq 0$ ;

(12) $SF_i - \overline{SF}_i^L \geq 0$;

(13) $CC_i - \overline{CC}_i^L \geq 0$;

(14) $HF_i - \overline{HF}_i^L \geq 0$;

(15) $SF_i - \overline{SF}_i^U \leq 0$;

(16) $CC_i - \overline{CC}_i^U \leq 0$;

(17) $HF_i - \overline{HF}_i^U \leq 0$;

(18) $\sum_R \sum_T A_{rij_F t} - \overline{FT}_i^L \geq 0$ where $j = j_F$ is the fall moldboard tillage system option;

where

$\overline{FT}_i^L$ = lower bound on fall moldboard tillage practices in study aggregate i in acres;

$\bar{M}_i^U$ = upper bound on the number of dairy cows in study aggregate i;

$\overline{SF}_i^L$ = lower bound on the number of steers in study aggregate i; $\overline{SF}_i^U$ is an upper bound;

$\overline{CC}_i^L$ = lower bound on the number of cow-calf units in study aggregate i; $\overline{CC}_i^U$ is an upper bound;

$\overline{HF}_i^L$ = lower bound on the number of hog litters in study aggregate i, $\overline{HF}_i^U$ is an upper bound;

The last eight restrictions are imposed in the baseline solution and, except for (18), in the subsequent policy solutions. These bounds serve two purposes. In the baseline solution they force the model's results to be representative of existing crop and livestock production activities. In some cases, this requires a lower bound and in others, an upper bound. Such bounding is necessitated when the baseline solution does not yield representative activity levels either as a result of data imperfections or objectives not incorporated into the model but affecting the behavior of farmers. In particular, capacity estimates were used to limit unrealistically large swings in livestock numbers. High fixed costs evident in livestock production tend to keep producers in the market during unprofitable periods and keep others from entering production during profitable periods. Capacity bounds allow the model to generate livestock production that is more comparable to current production and historical trends.

Appendix Table A. Farmer Options for Rotations, Tillage Systems, and Practices

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Rotations

1) Continuous corn

2) CM

3) CCOMM

Tillage Systems

1) Moldboard plow in fall

2) Chisel plow in fall

3) Chisel plow in spring

4) Spring disc

5) Slot planter

Practices

1) Straight row (up and down)

2) Contour

3) Terrace

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